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Glossary

absolute angle: an angle measured to a non-moving (inertial) frame of reference

acceleration: the rate of change of velocity (vector)

accelerometer: a device that measures acceleration

actin: the thin filaments in a myofibril that interact with myosin to create muscle tension

accommodation: a decrease in biological response to an unchanging stimulus

action potential: the electrical potential change during depolarization of nerves and activated muscle fibers

active tension: the tension created by the contractile component (actin–myosin interaction) of activated muscle

affine scaling: image scaling technique used to measure in a plane not perpendicular to the optical axis of the camera in 2D cinematography/videography

agonist: an anatomical term referring to the concentric action of a muscle or muscle group for presumed to create a specific movement

aliasing: distortion of a signal by an inadequate sampling rate

analog-to-digital (A/D) conversion: the process of taking a continuous signal and sampling it over time (see "sampling rate") to create a digital (discrete numbers) representation

anatomy: the study of the structure of the body

angle–angle diagram: a kinematic graph of one variable plotted against another (not time) that is useful in the study of coordination of movements

angular acceleration: the rate of change of angular velocity (vector)

angular displacement: the change in angular position (vector)

angular momentum: the quantity of angular motion, calculated as the product of the moment of inertia times the angular velocity (vector)

angular velocity: the rate of change of angular displacement (vector)

angular impulse: the angular effect of a torque acting over time: the product of the torque and the time it acts (vector)

anisotropic: having different mechanical properties for loading in different directions

antagonist: an anatomical term referring to a muscle or muscle group that is presumed to oppose (eccentric action) a specific movement

anthropometry: the study of the physical properties of the human body

aponeurosis: connective tissue within muscle and tendon in the form of a flat sheet

Archimedes' principle: the magnitude of the buoyant force is equal to the weight of the fluid displaced

arthrokinematics: the major, freely moveable rotations allowed at joints

balance: a person's ability to control their body position relative to some base of support

balance principle: a biomechanical application principle which states that the stability and mobility of a body position are inversely related

ballistic: explosive, momentum-assisted movement

bandpass filter: a filter designed to pass a range (bandpass) of frequencies, removing frequencies above or below this desirable range

bending: a combination of forces on a long body that tends to bend or curve the body creating tensile loads on one side and compression loads on the other side

Bernoulli's principle: the pressure a fluid can exert decreases as the velocity of the fluid increases

Bernstein's problem: a theory of motor control in which skill learning involves the reduction of redundant degrees of freedom**bilateral deficit**: simultaneous activation of two limbs that causes less force generation than the sum of the two individually activated limbs

biomechanics: study of the motion and causes of motion of living things

boundary layer: the layers of a fluid in close proximity to an object suspended in the fluid

buoyancy: the supporting or floating force of a fluid

center of buoyancy: the point at which the buoyant force acts

center of mass/gravity: the point that represents the total weight/mass distribution of a body; the mass centroid is the point where the mass of an object is balanced in all directions

center of percussion: a point on a striking object where impact with another object results in no reaction force at an associated point on the grip (see "sweet spot")

center of pressure: the location of the vertical ground reaction force vector; the center of pressure measured by a force platform represents the net forces in support and the COP may reside in regions of low local pressure

coactivation: simultaneous activation of agonist and antagonist muscles (co-contraction)

coefficient of drag: a measure of the relative fluid resistance between an object and a fluid

coefficient of friction: a measure of the resistance to sliding between the surfaces of two materials

coefficient of lift: a measure of the lift force that can be created between an object and a fluid

coefficient of restitution: a measure of the relative elasticity of the collision between two objects

common mode rejection: a measure of the quality of a differential amplifier in rejecting common signals (noise)

compression: a squeezing mechanical loading created by forces in opposite directions acting along a longitudinal axis

compliance: the ratio of change in length to change in applied force, or the inverse of stiffness (see "stiffness"); a material that is easily deformed has high compliance

components: the breaking up of a vector into parts, usually at right angles

concentric muscle action: the condition where activated muscles create a torque greater than the resistance torque (miometric)

conservation of energy: the Law of Conservation of Energy states that energy cannot be created or destroyed; instead, energy is transformed from one form to another

contourgram: exact tracings of the body positions of a movement from film/video images

contractile component: a part of the Hill muscle model that represents the active tension and shortening of actin and myosin

coordination continuum: a biomechanical application principle which states that movements requiring generation of high forces tend to utilize simultaneous segmental movements, while lower-force and high-speed movements tend to use sequential movements

couple: (1) two forces of equal size, parallel lines of actions, and opposite sense; (2) a mechanical calculation tool that is employed to represent torques without affecting linear kinetics

creep: the increase in length (strain) over time as a material is constantly loaded

cross-talk: the pick-up of EMG signals from other active muscles aside from the muscle of interest

cut-off frequency: the cutting point of a filtering technique, where frequencies above or below are removed; the lower the cut-off frequency for a lowpass filter, the greater the smoothing of the signal

deformable body: biomechanical model that documents the forces and deformations in an object as it is loaded

density: the mass of an object divided by its volume

degrees of freedom: the number of independent movements an object may make, and consequently the number of measurements necessary to document the kinematics of the object

differential amplification: EMG technique for amplifying the difference between the signals seen at two electrodes relative to a reference electrode

digital filter: a complex frequency-sensitive averaging technique used to smooth or process data

digitize (video): the A/D conversion of an analog video signal to create the discrete picture elements (pixels) used to make a video image

digitize (biomechanics): the process of measuring 2D locations of points on an image

direct dynamics: biomechanical simulation technique where the kinematics of a biomechanical model are iteratively calculated from muscle activation or kinetic inputs

direct linear transformation (DLT): a short-range photogrammetric technique to create 3D coordinates (x,y,z) from the 2D coordinates (x,y) of two or more synchronized camera views of an event

displacement: linear change in position in a particular direction (vector)

distance: liner change in position without regard to direction (scalar)

double differential amplification: EMG technique to eliminate cross-talk

drag: the fluid force that acts parallel to the relative flow of fluid past an object

dynamic flexibility: the increase in passive tension per increase in joint range of motion

dynamical systems: motor learning theory which argues that movement coordination emerges or self-organizes based on the dynamic properties of the body and environment rather than on a central motor program from the brain

dynamics: the branch of mechanics studying the motion of bodies under acceleration

dynamometer: a device that measures force or torque for muscular performance testing

eccentric muscle action: the condition where an activated muscle(s) creates a torque less than the resistance (plyometric) torque

economy: the amount of energy needed to do a specific amount of work

efficiency: in a system, the ratio of work done to work input

elastic: the resistance of a body to deformation (see "stiffness")

elastic (strain) energy: the potential mechanical work that can be recovered from restitution of a body that has been deformed by a force (see "hysteresis")

electrogoniometer: a device that makes continuous measurements of joint angle(s)

electromechanical delay: the delay between motor action potential (electric signal of muscle depolarization or EMG) and production of muscular force

electromyography (EMG): the amplification and recording of the electrical signal of active muscle

energy (mechanical): the ability to do mechanical work (potential, strain, and kinetic energy are all scalar mechanical energies)

ergometer: machine used to measure mechanical work

Euler angles: a way to represent the 3D motion of an object using a combination of three rotations (angles)

excursion: the change in the length of a muscle as the joints are moved through their full range of motion

external force: a force acting on an object from its external environment

external work: work done on a body by an external force

fascicle: a bundle of muscle fibers (cells)

fast Fourier transformation (FFT): mathematical technique to determine the frequencies present in a signal

field (video): half of an interlaced video image (frame), composed of the even or odd horizontal lines of pixels

finite difference: calculating time derivative by discrete differences in kinematics divided by the time between datapoints

finite-element model: advanced biomechanical model to study how forces act within a deformable body

firing rate: the number of times a motor unit is activated per second

First Law of Thermodynamics: application of the Law of Conservation of Energy to heat systems

fluid: a substance, like water or gasses, that flows when acted upon by shear forces

force: a push, pull, or tendency to distort between two bodies

force–length relationship: skeletal muscle mechanical property that demonstrates how muscle force varies with changes in muscle length (also called the length–tension relationship)

force–motion principle: a biomechanical application principle which states that unbalanced forces are acting whenever one creates or modifies the movement of objects

force platform: a complex force transducer that measures all three orthogonal forces and moments applied to a surface

force–time principle: a biomechanical application principle which states that the time over which force is applied to an object affects the motion of that object

force–time relationship: (see "electromechanical delay")

force–velocity relationship: skeletal muscle mechanical property that shows how muscle force potential depends on muscle velocity

Fourier series: a mathematical technique for summing weighted sine and cosine terms that can be used to determine frequency content or represent a time domain signal

frame (video): a complete video image

free-body diagram: a technique for studying mechanics by creating a diagram that isolates the forces acting on a body

frequency: the inverse of time or the number of cycles of an event per second

frequency content: time-varying signals can be modeled as sums of weighted frequencies (see "Fourier series")

frequency response: the range of frequencies that are faithfully reproduced by an instrument

friction: the force in parallel between two surfaces that resists sliding of surfaces past each other

global reference frame: measuring kinematics relative to an unmoving point on the earth

Golgi tendon organ: a muscle receptor that senses muscle tension

goniometer: a device used to measure angular position

gravity: the force of attraction between objects; usually referring to the vertical force of attraction between objects and the earth

ground reaction force: the reaction (opposite) forces created by pushing against the ground (e.g., feet in running or hands in a handstand)

harmonic: a multiple of a fundamental frequency (see "frequency content")

helical (screw) axis motion: a way to represent the 3D motion of an object using an imaginary axis in space and rotations relative to that axis

highpass filter: a signal-processing technique that removes the low-frequency components of a signal

Hill muscle model: a three-component model of muscle force consisting of a contractile component, a series elastic component, and a parallel elastic component

hypertrophy: the increase in size of muscle fibers

hysteresis: the energy loss within a deformed material as it returns to its normal shape

impulse: the mechanical effect of a force acting over time (vector); $\mathbf{J} = \mathbf{F} \cdot t$

impulse–momentum relationship: principle which states that the change in momentum of an object is equal to the net impulse applied; the original language of Newton's second law, and equivalent to the instantaneous version: $\mathbf{F} = m\mathbf{a}$

inertia: the property of all matter to resist a change in its state of motion

inertial force: the mass acceleration (m$\mathbf{a}$) term in Newton's Second Law (dynamics); the effect of inertia and acceleration on dynamic movement, but it is important to remember that its effect is not a real force acting on an object from another object

inertia principle: A biomechanical application principle which states that inertial resistance to changes in state of motion can be used to advantage in resisting motion or transferring energy

information: observations or data with unknown accuracy

in situ: Latin for "in place", or structures isolated by dissection

integrated EMG (IEMG): the area under a rectified EMG signal; correctly, the time integral reported in units of amplitude $\times$ time (mV·s); unfortunately, some studies employ outdated equipment and incorrect terminology, so that reported IEMGs are not really integrated but filtered or smoothed EMG values (mV), which is essentially a linear envelope detector

interdisciplinary: the simultaneous integrated application of several disciplines to solution of a problem

internal force: a force within an object or between the molecules of an object

internal work: work done on body segments by internal forces (muscles, ligaments, bones)

inverse dynamics: biomechanics research technique for estimating net forces and moments in a linked-segment model from measured kinematics and anthropometric data

in vitro: Latin for "in glass," or tissues removed from the body but preserved

in vivo: Latin for "in the living," or during natural movement

isokinetic ("same, or constant, motion"): the condition where activated muscles create constant joint angular velocity

isometric ("same, or constant, length"): the condition where activated muscles create a torque equal to the resistance torque, so there is no joint motion

isotonic ("same, or constant, tension"): the condition where activated muscles work against a constant gravitational resistance; muscle tension is *not* constant in these conditions

jerk: the third derivative of displacement with respect to time

joint center: an approximation of the instantaneous center of rotation of a joint

joint reaction forces: the net forces acting at joints calculated from inverse dynamics; these forces do not represent the actual bone-on-bone forces acting at joints, but a combination of bone, muscle, and ligament forces

Joule: the unit of mechanical energy and work

kinematic chain: a linkage of rigid bodies; an engineering term used to simplify the degrees of freedom needed to document the mechanical behavior of a system; Steindler (1955) proposed the terminology of a kinetic chain, and classifying chains as either open or closed; unfortunately, this has resulted in a great deal of confusion and an unclear manner of classifying movements/exercises: **open**: one end link is free to move; **closed**: constraints (forces) on both ends of the kinematic chain

kinematics: the branch of mechanics that describes the motion of objects relative to some frame of reference

kinetic energy: the capacity to do work due to the motion of an object

kinetics: the branch of mechanics that explains the causes of motion

knowledge: the contextual, theory-based and data-supported ideas that make the best current explanation for reality

laminar flow: movement of fluid in smooth, parallel layers

Law of Acceleration: Newton's Second Law of Motion, which states that the acceleration an object experiences is proportional to the resultant force, is in the same direction, and is inversely proportional to the object's mass ($\Sigma \mathbf{F} = m\mathbf{a}$)

Law of Inertia: Newton's First Law of Motion, which states that objects tend to resist changes in their state of motion; formally, we say an object will remain in a state of uniform motion (stillness or constant velocity) unless acted upon by an external force

Law of Momentum: Newton's second law written as the impulse–momentum relationship

Law of Reaction: Newton's Third Law of Motion, which states that for every force there is an equal and opposite reaction force

lever: a simple machine used to magnify motion or force; a lever consists of a rigid object rotated about an axis

lift: the fluid force that acts at right angles to the relative flow of fluid

linear envelope: EMG processing technique where a rectified signal is smoothed with a lowpass filter

linearity: a measure of the accuracy of an instrument, usually expressed as a percentage of full-scale output (FSO)

linear voltage differential transducer (LVDT): a force-measuring device

linked-segment model: a rigid body model linked together by joints

load: a force or moment applied to a material

load cell: a force-measuring device

load-deformation curve: the mechanical behavior of a material can be documented by instantaneous measurement of the deformation and load applied it

local reference frame: measuring kinematics relative to a moving point, or nearby rigid body (joint, segment, or center of mass)

lowpass filter: a signal-processing technique that removes the high-frequency components of a signal

Magnus effect: the creation of lift force on a spinning sphere

markers: high-contrast reflective materials attached to subjects to facilitate the location of segments, landmarks, or joint centers for digitizing

mass: the resistance of an object to linear acceleration

maximal voluntary contraction (MVC): the maximum force/torque a person can create with a muscle group, usually under in isometric conditions

mechanical advantage: a ratio describing the effectiveness of a lever calculated by the moment arm for the force divided by the moment arm for the resistance

mechanics: the branch of physics that deals with forces and the motion they create

mechanomyography (phonomyography, vibromyograph): the amplification and recording of the vibrations created by muscle activation

modeling: mathematical representations of the biomechanical systems used for calculations or simulations

moment (moment of force, torque): the rotating effect of a force

moment arm: the leverage of a force for creating a moment; the perpendicular distance from the axis of rotation to the line of action of the force

moment of inertia: the resistance to rotation (angular acceleration) of a body

momentum: the quantity of motion of an object calculated by the product of mass and velocity (vector)

motor action potential: the change in electrical charge about a muscle fiber as it is activated

motor unit: a motor neuron and the muscle fibers it innervates

muscle action: the activation of muscle to create tension that contributes to joint movement or stabilization

muscle inhibition: the inability to fully activate or achieve maximum muscle force during maximum voluntary contraction

muscle spindle: an intramuscular receptor that senses changes in muscle length

myofibril: the small cylindrical filaments that make up a muscle fiber/cell

myosin: the large filaments in a myofibril that interact with actin to create muscle tension

myotatic reflex: a short reflex arc that activates a muscle as it is stretched

net force: the resultant force or sum of all external forces acting on an object

Newton: the SI unit of force; 1 Newton (N) is equal to 0.22 pounds

normal reaction: the force acting at right angles to the surfaces of objects that are in contact

Nyquist frequency: a signal sampling theorem which states that the minimum digital sampling rate (Nyquist frequency) needed to accurately represent an analog signal is twice the highest frequency present in the signal

optimal projection principle: A biomechanical application principle which states that there are ranges of optimal angles for projecting objects to achieve certain goals

orthogonal: perpendicular (at right angles)

orthotics: objects/braces that correct deformities or joint positioning

overuse injury: an injury created by repetitive movements below acute injury thresholds, but due to inadequate rest and/or repetitive stress, injury develops; also known as cumulative trauma disorder or repetitive motion injury

parallel elastic component: a part of the Hill muscle model that represents the passive tension from connective tissue throughout the muscletendon unit

Pascal: the SI unit of pressure or stress (force per unit area)

passive insufficiency: the limitation of joint motion because of increases in passive tension in multiarticular muscles stretched across multiple joints

passive tension: a component of muscle tension from passive stretching of muscle, especially the connective tissue components

pennation: the angle of muscle fiber bundles relative to a tendon

piezoelectric: crystals with electromechanical properties that can be used to measure force/acceleration

point mass: a simplified mechanical model that represents an object as a point in space with a given mass

potential energy: the capacity to do work of an object due to its vertical position in a gravitational field (gravitational potential energy) or its deformation (strain energy)

potentiometer: a device that is used to measure rotation

power (mechanical): the rate of doing mechanical work; peak mechanical power represents the greatest mechanical effect, the ideal combination of force and velocity; power can be calculated as $\mathbf{W}/t$ or $\mathbf{F} \cdot \mathbf{V}$

preamplification: the amplification of small signals (EMG) close to their source before they are conducted to other devices for amplification and recording

pressure: external force divided by area over which the force acts

projectile: an object projected into space without self-propulsion capability, so the only forces acting on the object are gravity and air resistance

proprioceptive neuromuscular facilitation (PNF): specialized stretching procedures that utilize sequences of muscle actions to potentiate reflexes to relax muscles being stretched

prosthetics: artificial limbs

Pythagorean Theorem: the two sides of a right triangle forming the right angle (a and b) and the hypotenuse (c) are related as follows: $a^2 + b^2 = c^2$

qualitative analysis: systematic observation and introspective judgment of the quality of human movement for the purpose of providing the most appropriate intervention to improve performance (Knudson & Morrison, 2002)

quantitative analysis: solving a biomechanical problem using numerical measurements and calculations

quasistatic: the state of a mechanical system where the accelerations are small enough to be assumed equal to zero

radian: a dimensionless unit of rotation equal to 57.3°

radius of gyration: a convenient way to summarize an object's moment of inertia, defined as the distance from the axis of rotation at which half the object's mass must be placed in both directions to equal the object's moment of inertia

range-of-motion principle: a biomechanical application principle which states that the amount of linear and angular motion used will affect the speed and accuracy of human movement

reaction change: a method to calculate the center of gravity of static body postures

reciprocal inhibition: the inhibition of an opposing muscle group (antagonist) when a muscle group (agonist) is activated

recruitment: activation of motor units of muscles by the central nervous system

rectified EMG: a processing technique that converts negative EMG voltages to positive ones

redundancy (distribution) problem: a mathematical problem with most kinetic biomechanical models, where there are more musculoskeletal unknowns than there are equations

relative angle: an angle measured between two moving objects

residuals: difference between a smoothed and raw signal; can be used to examine the quality of the fit of the new signal to the pattern of the raw signal

resolution (video): the number of pixels available to measure a given field of view; a video image of a 3-meter wide area with a horizontal resolution of 640 pixels has a resolution for measurement of about 5 mm

resonance: frequency of vibration that matches the physical properties of a body so that the amplitudes of the vibration increase rather than decay over time

resting length: the middle of muscle range of motion where passive tension begins to rise

resultant: the addition of vectors to obtain their net effect (see "net force")

right-hand rule: a convention or standard for drawing the correct direction of angular velocity vectors

rigid body: mechanical simplification (abstraction) assuming the dimensions of an object do not change during movement or loading

root mean square (RMS): signal processing calculation that approximates the mean absolute value of a time-varying signal

rotator cuff: the four deep, stabilizing muscles of the glenohumeral joint: the infraspinatus, supraspinatus, subscapularis, and teres minor

sampling rate: the number of discrete samples per second used to represent a signal; NTSC video has an effective sampling rate of 60 Hz or 60 fields per second

sarcomere: the functional unit of a myofibril; a sarcomere is the region between two Z disks

scalar: simple quantity completely defined by a single number (magnitude)

scaling: converting image measurements to actual size

science: a systematic method for testing hypotheses with experimental evidence for the purpose of improving our understanding of reality

Second Law of Thermodynamics: no machine can convert all the input energy into useful output energy

segmental interaction principle: a biomechanical application principle which states that forces acting in a system of linked rigid bodies can be transferred through the links

segmental method: a research method used to calculate the center of gravity of a body using anthropometric data, joint coordinates, and static equilibrium

series elastic component: a part of the Hill muscle model that represents the passive tension of connective tissue in series with the contractile component

shear: mechanical loading in opposite directions and at right angles to the surface of a material

shutter speed: the period of time during which a photographic or video image is captured (e.g., 1/1000 of a second); limiting this period can prevent blurring of moving objects

simulation: use of a biomechanical model to predict motion with given input conditions in order to study the factors that affect motion (see "direct dynamics")

size principle: the orderly recruitment of motor units occurs from the smallest to the largest

smoothing: a processing technique that smooths data, removing rapid fluctuations that are not part of normal biomechanical signals

smoothing parameter: an index of the amount of smoothing allowed in splines; the larger the smoothing parameter, the more smoothing (allowable deviation between the raw and fitted curve)

snap: the fourth derivative of displacement with respect to time

speed: the rate of change of distance (scalar)

spin principle: a biomechanical application principle which states that spin is put on a projectile to affect trajectory or bounce

spline: a smoothing technique that replaces the signal with several polynomials linked together; cubic (third power) and quintic splines (fifth power) are common in biomechanics

static equilibrium: when all the forces and torques acting on an object sum to zero, meaning that the object is motionless or moving at constant velocity

static flexibility: the linear or angular measurement of the limits of motion in a joint or joint complex

statics: the branch of mechanics that studies bodies at rest or in uniform motion

stiffness: the elasticity of a material, measured as the slope of the elastic (linear) region of the stress–strain curve (Young's modulus of elasticity); a material's stiffness is usually approximated using the slope of the linear region of the load-deformation curve

strain (mechanical): the amount of deformation of a material caused by an applied force, usually expressed as a percentage change in dimensions

strain (muscular): muscular injury usually caused by large eccentric stretches of muscle fibers

strain energy: the capacity to do work of an object due to its deformation by an external force

strain gauge: a small array that is bonded to materials in order to sense the small changes in size (strain) as the material is loaded; usually used to measure force or acceleration

strength (mechanical): the toughness of a material to resist loading, usually measured as the total work or peak force required to permanently deform (yield strength) or break a material (ultimate strength)

strength (muscular): the maximum force or torque produced by a muscle group in an isometric action at a specific joint angle; research has found several domains of strength expression depending on the time, velocity, and resistance involved

stress (mechanical): the force per unit area in a material

stress fracture: a very small fracture in cortical bone caused by repetitive loading and inadequate rest

stress relaxation: the decrease in stress in a material over time when subjected to a constant force

stress–strain curve: (see "load deformation")

stretch-shortening cycle (SSC): a common coordination strategy where agonists for a movement are eccentrically loaded in a countermovement, immediately before the concentric action and motion in the intended direction; an SSC results in larger initial forces and greater concentric work than purely concentric actions

synergy: the combination of several muscle actions that serve to optimally achieve a motor task

sweet spot: striking implements (bats, rackets, etc.) have zones where impact with other objects is most effective; the term *sweet spot* tends to refer to the zone with the highest coefficient of restitution, although there are zones that minimize reaction forces (center of percussion), or minimize vibration (node)

technology: the tools and methods for applying scientific knowledge to solve problems or perform tasks

telemetry: a technique to send biomechanical signals to recording devices without wires, using an FM radio transmitter and receiver

tension: a pulling apart (making longer) of mechanical loading created by forces in opposite directions acting along the longitudinal axis of a material

tensor: a complex variable that cannot be described using only magnitude and direction

tetanus: the summation or fusion of many twitches of muscle fibers into a smooth rise in tension

thixotropy: a property of a material to change passive stiffness in response to previous loading; this history-dependent behavior is apparent in the increasing stiffness of muscle with extended inactivity

time constant: typically, an averaging/smoothing value in EMG processing; the larger the time constant the larger the time interval averaged over, meaning more smoothing

torque (see "moment of force"): the rotating effect of a force; mechanics of materials uses torque to refer to torsion moments acting on an object

torsion: opposing loads that twist an object along its longitudinal axis

trajectory: the path in space that an object follows as it moves through the air

twitch: the force response of a muscle fiber to a single stimulation

twitch interpolation (superimposition) technique: a method used to determine the maximality of a maximum voluntary action (MVC) where stimulation is provided during an MVC

vector: a complex quantity requiring description of size and direction

viscoelastic: the property of a material where force in the material is dependent on time and deformation

weight: the downward (vertical) force action on an object due to gravity

Wolff's Law: bones remodel according to the stress in the tissue

work (mechanical): work is done when a force moves an object in the direction of the force and is calculated as the product of force and displacement

work–energy relationship: principle in physics which states that the work done on a body is equal to the net change in energy in the body

yield point: point on the load-deformation curve where a material continues to deform without increasing load

Young's modulus (see "stiffness")

Conversion Factors

Biomechanical variables are reported in traditional English units and the metric system (SI, International System). The conversion factors below appendix are useful for converting between various measurement units. It is likely you will find one unit of measurement easier to relate to, and you may need to transform some values from the literature to more convenient units of measurement.

For example, if you wanted to get a feel for how fast a person is running at 9 m/s, you could take 9 m/s times 2.23 to get 20.1 mph. If you wanted to know how fast you were running on a treadmill that reported your pace as 8.5 minutes per mile, you would first convert the pace to an average speed in miles per hour. Sixty minutes divided by 8.5 minutes would equal 7.1 mph. Next you would take 7.1 mph divided by the conversion factor (2.23) to obtain 3.2 m/s.

Variable	SI unit	×	Factor	=	Other unit
distance	m		3.28		ft
	km		0.621		miles
	radian		57.3		degrees
speed	m/s		2.23		mph
	km/hr		0.62		mph
	m/s		3.28		ft/s
	rad/s		57.3		deg/s
	rad/s		9.55		rpm
acceleration	m/s/s		0.102		g's
mass	kg		0.069		slugs
moment of inertia	kg·m^2		0.738		slugs·ft^2
force	N		0.225		pounds
torque	N·m		0.738		lbs·ft
impulse	N·s		0.225		lbs·s
energy	Joules		0.738		ft·lbs
work	Joules		0.738		ft·lbs
power	Watts		1.341		horsepower
momentum	(kg·m)/s		0.225		(slug·ft)/s
	(kg·m^2)/s		0.225		(slug·ft^2)/s
stress/pressure	Pascals		0.00015		lbs/in^2

Suggested Answers to Selected Review Questions

This appendix provides initial answers to, primarily, the odd-numbered review questions from chapters 1 through 8. The purpose of review questions is to practice and rehearse key biomechanical concepts, principles, and laws. Students are encouraged to study the topics related to each question in greater depth. The discussion questions in chapters 9 through 12 are designed for students and instructors to discuss. Discussion questions are ideal for small-group brainstorming and practice in qualitative analysis of human movement.

Chapter 1

1. Biomechanics is the study of how living things move using the science of mechanics. In the first half of the twentieth century this was synonymous with kinesiology, but now kinesiology is the academic discipline of the study of human movement.

3. The advantages of qualitative biomechanical analysis is its ease of use and flexibility, but its weaknesses are related to subjectivity and reliability. Quantitative biomechanical analysis may have greater precision and accuracy, but its weaknesses are the high cost in terms of equipment and time.

5. A wide variety of journals publish biomechanics research. These journals include specialized biomechanics, engineering, biology, medicine, strength and conditioning, and sports-medicine journals.

7. Biomechanics must be integrated with other kinesiology sciences because people are not robots that move without regard to environmental factors. Psychological, physiological, and perceptual issues are all examples of factors that might be more important than biomechanical factors in some situations.

Chapter 2

1. Biomechanics has traditionally focused on rigid body and fluid mechanics. The majority of early biomechanical studies focused on the kinematics of movement, but there are still many studies on the causes (kinetics) of movement.

3. Scalars only require knowledge of size and units. Vector variables have size, units, and direction.

5. The nine principles of biomechanics can be subdivided into principles related to human movement and projectiles.

7. Many factors affect human movement along with the principles of biomechanics. Some factors might be performer characteristics (psychological, perceptual, or social), the physical environment, the goal of the movement, and the philosophical goals of the kinesiology professional.

Chapter 3

1. There are several anatomical terms employed to describe the location and mo-

tion of body structures. Some examples include directions (anterior/posterior, medial/lateral, superior/inferior, proximal/distal) and joint movements (flexion/extension, adduction/abduction, internal rotation/external rotation).

3. Muscle fiber types and their architectural arrangement affect muscle force and range of motion. The rise and decay of muscle tension is greatest in fast-twitch fibers and decreases the greater the oxidative or slow-twitch characteristics of the fiber. Muscle fibers arranged in parallel have greater range of motion but create less force. Pennate fiber arrangements produce greater force but have less range of motion.

5. Muscle tension has active and passive components. Passive tension does not appear to play a large role in the middle of the range of motion, but does tend to limit motion when the muscle is stretched near the end of the range of motion.

7. Examples of the force–motion principle can be seen anytime an object changes its state of motion. If a dumbbell reverses direction at the bottom of an arm curl exercise, we can conclude an unbalanced upward force was applied to the dumbbell.

9. Biomechanical principles and research help the kinesiology professional to understand how human movement occurs and how movement might be improved. The major areas of biomechanics research that are the most valuable in this area are EMG, studies of anatomical variation, linked segment interactions, and modeling and simulation.

Chapter 4

1. The primary loads on body tissues are compression, tension, and shear. The combined loads are bending and torsion.

3. The tensile strengths of tendon and muscle are about 14,500 and 60 lb/in^2, respectively, while the tensile strength of bone is about 18,000 lb/in^2. These data are consistent with the higher incidence of muscle injuries compared to that for tendon or bone.

5. The Force–Velocity Relationship has several implications for resistances and speed of movement in strength-training exercises. When training for muscular strength, large resistances should be moved slowly to train the muscle where it is strongest. Training for muscular power and endurance uses smaller resistances moved at faster speeds.

7. The Force–Time Relationship defines the delay between neuromuscular signaling for creation of muscle force and a rise in that force, while the force–time principle deals with duration of force application. While these two concepts are related, the force–time principle involves adapting the timing of the application of force by a person to the demands of the task while electromechanical delay is one of the factors that affects how force can be applied.

9. The brain creates muscle tension by recruitment of motor units and modifying their firing rate or rate coding. Motor units tend to have predominantly one fiber type, so that the brain generally recruits motor units based on the size principle, from slow-twitch motor units to fast-twitch motor units.

11. Muscle spindles sense stretch and golgi tendon organs sense muscle tension.

13. Large ranges of motion allow for greater production of speed and force, while smaller ranges of motion tend to allow for more accurate movement. The weight shifts in a golf swing and baseball batting are small because of the high accuracy demands of these skills. Maximizing range of motion in the countermovement in jumps is not usually effective because of timing limitations or biomechanically weak positions in deep knee flexion.

15. A person doing a seated knee extension exercise uses concentric action of the

quadriceps groups to extend the knee, and eccentric action of the quadriceps to flex the knee. The forces acting on the lower leg include muscle forces from the hamstrings, quadriceps, ankle muscles, and gravity. If the person were exercising on a machine there would be forces applied to the leg/ankle from the machine.

Chapter 5

1. The frame of reference is the point from where motion is measured.

3. An average velocity is a velocity estimate for the middle of a time interval where displacement and time information are available ($V = d/t$). The smaller the time interval used for the calculation, the more accurate the average velocity is and the closer it gets to true instantaneous velocity. An instantaneous velocity is an exact estimate of the velocity at an instant in time, and is calculated using calculus.

5. With upward displacement as positive, the average vertical velocity ($V = d/t$) of the dumbbell for the concentric phase is $1.2/1.5 = 0.8$ m/s , while the average vertical velocity of the eccentric phase is $-1.2/2.0 = -0.6$ m/s.

7. Angular kinematics are particularly suited for analysis of human movement because joint motions are primarily rotational. Markers placed on the body can by digitized to calculate the angular kinematics of the joints during human movements.

9. Since knee extension is positive (+50 deg/s), the angular acceleration of her knee ($\alpha = \omega/t$) is: $(0 - 50)/0.2 = -250$ deg/s/s.

11. The coach could use a radar gun to measure maximum and warm-up throwing speeds. If the coach did not have a radar gun, they could measure off the standard distance and time of the throws with a stopwatch to calculate average velocities in each throwing condition.

13. To use the angular-to-linear velocity conversion formula ($V = \omega \cdot r$), the angular velocity must be in radian/second: 2000 deg/s divided by 57.3 deg (1 radian), which is equal to 34.9 radian/s. The velocity of the club head relative to the golfer's hands is: $34.9 (1.5) = 52.4$ m/s.

15. The vertical acceleration of a volleyball anywhere in flight is a downward acceleration due to gravity of -9.8 m/s/s or -32.2 ft/s/s.

Chapter 6

1. A 6-kg bowling ball has the same inertia in all states of motion. The ball's inertia is a fundamental property of matter and is measured by its mass, 6 kg. This will not change unless we get the ball rolling near the speed of light!

3. Increasing inertia is useful in movement when you want to maximize stability, or if there is time to get a larger inertia moving in a desired direction. Increasing the mass of a wrestler will make it more difficult for an opponent to move the wrestler.

5. The major determining factors of dry friction are the normal reaction and the coefficient of friction. Since adding mass to a person has other effects, the best strategy is to select a shoe with a higher coefficient of friction with common flooring.

7. If we move the shearing force to the left, we create a right triangle with a 30° angle on the right and a hypotenuse of 1000 N. The longitudinal component of the joint force (F_L) is the adjacent side, so we can use the cosine relationship to calculate: cos 30° $= F_L/1000$, so $F_L = 866$ N. The sine of 30° is a special value (0.5), so we can quickly see that $F_S = 500$ N.

9. Muscular strength is the maximum force a muscle group can create in certain conditions, usually an isometric action at a specified joint angle. Muscular power is the rate of doing muscular work. Maximum

muscular power occurs at the combination of velocity and force that maximizes muscular work. This usually occurs at moderate (about a third of maximum) velocities and muscular force.

11. Given a 800-N climber has 81.6 kg (800/9.8) of inertia and upward displacement is positive, we can use Newton's second law in the vertical direction ($F = m\mathbf{a}$) to calculate: $-800 + 1500 = 81.6(\mathbf{a})$, so $\mathbf{a} = 8.6$ m/s/s.

13. Sequential coordination of high-speed movements is advantageous because initial proximal movement contributes to SSC muscle actions, and mechanical energy can be transferred through segmental interaction.

15. Given that an upward displacement is positive and a 30-kg barbell weighs –294 N (30 · 9.8), we can use Newton's second law in the vertical direction ($F = m\mathbf{a}$) to calculate: $-294 + 4000 = 30(\mathbf{a})$, so $\mathbf{a} = 123.5$ m/s/s or 12.6 g's of vertical acceleration.

Chapter 7

1. A torque or moment of force depends on the applied force and the moment arm.

3. The joints of the human body allow us to change our resistance to rotation or moment of inertia by moving the masses of the body segment towards or away from an axis of rotation. Bringing segments close to an axis of rotation decreases moment of inertia while extending segments away from an axis of rotation increases moment of inertia.

5. Newton's first angular analogue says that an object will stay at rest or constant rotation unless acted upon by an external torque. Newton's second angular analogue says that the angular acceleration of an object is proportional to the torque causing it, is in the same direction, and is inversely proportion to the moment of inertia. Newton's third angular analogue states that for every torque acting on an object there is an equal and opposite torque this object applies back on the other object creating the torque.

7. The center of gravity of athletes doing a lunge-and-sprint start as illustrated below are likely the positions indicated by the dot.
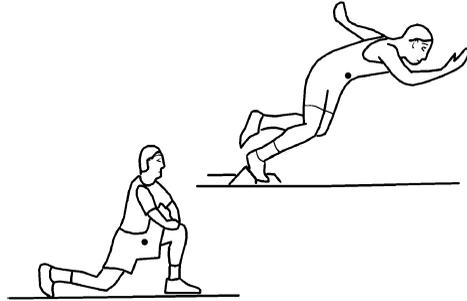
9. To maximize stability, a person can increase the size of the base of support, lower the center of gravity relative to the base of support, and position the center of gravity relative to anticipated forces. Maximizing stability tends to decrease the ability to move in all directions (mobility).

11. Given that the force applied by the student was 30 lb and we know the radius of the merry-go-round, it is easiest to find the rotary component ($\mathbf{F_R}$) of the force to multiply by the radius (4 ft) to obtain the torque applied. We can calculate: $\cos 55° = \mathbf{F_R}/30$, so $\mathbf{F_R} = 17.2$ lb. Torque ($\mathbf{T} = \mathbf{F} \cdot \mathbf{d_\perp}$) applied to the merry-go-round is: $17.2(4) = 68.8$ lb·ft. This is almost half the 120 lb·ft of torque when the force is applied at an angle that maximizes the moment arm.

13. You cannot calculate the torque because the muscle angle of pull is not known.

Chapter 8

1. The major fluid forces are buoyancy, lift, and drag. Buoyancy acts upward. Drag acts parallel to and opposing the relative

flow of fluid, while lift acts at right angles to the relative flow of fluid.

3. The center of gravity and center of buoyancy of the human body move in similar manner, following the mass shifts with moving segments. The center of gravity moves more than the center of buoyancy because the trunk volume dominates the volume of the rest of the body.

5. Optimal projection angles include the effect of fluid forces as well as the release and target locations of projection activities. For example, place-kicking has an optimal angle of projection much lower than 45° because of the fluid forces of drag.

7. The centers of buoyancy of a swimmer in three flotation positions (below) are likely the positions indicated by the dot.

9. A volleyball serve with topspin dives downward because the Magnus Effect generates a downward-and-backward-directed lift force that adds to gravity.

11. Round balls tend to curve in the direction of the spin. If the front of a ball is spinning to the right (as you observe it as it is coming toward you), the lift force will act to the right and make the ball curve to the right.

13. Swimmers and cyclists shave so as to decrease surface drag, which resists their motion, while a rougher surface of a spinning baseball will create a greater lift force. The greater Magnus Effect and lift force acting on the baseball is more important than the minor effect the roughness will have on drag.

Right-Angle Trigonometry Review

Trigonometry is a branch of mathematics that is particularly useful in dealing with right-angle triangles. This is important in the study of biomechanics because vectors are usually resolved into right-angle components. This appendix provides a brief review of four trigonometric relationships for two-dimensional analysis in the first quadrant. There are many more trigonometric relationships that are fully defined for all 360° of a circle. The four relationships will be defined relative to right triangle illustrated below.

The sides of a triangle are traditionally labeled in two ways, with letters and names describing their position relative to one of the acute angles of interest (θ). The longest side of the triangle is the **hypotenuse** or **c**. The side next to the angle of interest is usually labeled **a** or the **adjacent** side. The last side is the **opposite** side or **b**.

The first relationship is the **Pythagorean Theorem**, which describes the relationship between the lengths of the sides in all right triangles. If you have knowledge of any two of the three sides of a triangle you can apply the formula $c^2 = a^2 + b^2$ to solve for the magnitude of the other side.

The sine, cosine, and tangent are the most commonly used trigonometric relationships, because they define the relationships between the acute angles and the dimensions of right triangles. The abbreviation and formula for each relationship is:

$$\sin \theta = b/c$$
$$\cos \theta = a/c$$
$$\tan \theta = b/a$$

Suppose the right triangle depicted below corresponds to the following data on the release conditions of a soccer kick: c = 40 m/s and θ = 35°. A biomechanist wanting to determine the vertical velocity (b) in order to determine the time of flight could write:

$$\sin 35° = V_V/40,$$

and solving could yield

$$V_V = 22.9 \text{ m/s}$$

Now use the cosine, tangent, or Pythagorean Theorem to see if you can confirm if the horizontal velocity of the ball is 32.8 m/s.
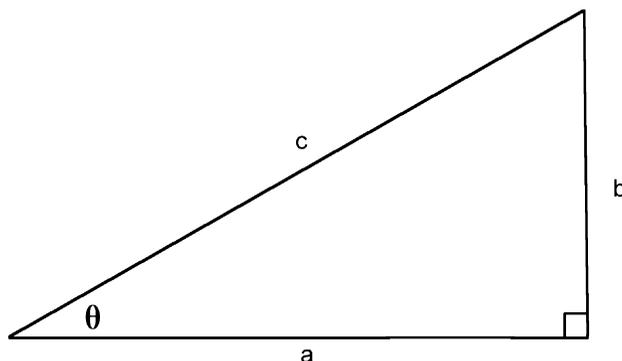
Qualitative Analysis of Biomechanical Principles

Principle	Body part	Rating (inadequate-normal-excessive)
Balance		
Coordination		
Force–Motion		
Force–Time		
Inertia		
Range of Motion		
Segmental Interaction		
Optimal Projection		
Spin		

Index

Lab Activities

This section of the book provides applied laboratory activities. These labs are designed to illustrate key points from the chapters of the text. The labs are also designed to be flexible enough to be used as full labs for universities with 4-credit courses or as short activities/demonstrations for 3-unit courses. The emphasis is on using actual human movements and minimal research equipment. While quantitative measurements and calculations are part of some labs, most of them focus on students' conceptual understanding of biomechanics and their ability to qualitatively analyze human movement. Most labs are structured for work in small groups of three to five students.

Citations of background information are provided for students to prepare for the labs. Space does not allow for all relevant research citations to be included on each two-page lab. If instructors assign background reading prior to labs, they should assign specific sections of the resources suggested. I am indebted to many of my peers who have shared their teaching ideas at professional meetings, especially those who have attended and contributed to the last few national conferences on teaching biomechanics.

LAB ACTIVITY 1

FINDING BIOMECHANICAL SOURCES

Biomechanics is the study of the causes of biological movement. Biomechanics is a core sub-discipline of kinesiology, the academic study of human movement. All kinesiology professions use biomechanical knowledge to inform their practice. Both scholarly and professional journals publish biomechanical research. There are many people interested in biomechanics, so biomechanical literature is spread out across many traditional scholarly areas. This lab will help you appreciate the breadth of biomechanics in your chosen career, and provide you with experience in finding biomechanical sources.

BACKGROUND READING

Chapter 1 herein: "Introduction to Biomechanics of Human Movement"

Ciccone, C. D. (2002). Evidence in practice. *Physical Therapy*, **82**, 84–88.

Minozzi, S., Pistotti, V., & Forni, M. (2000). Searching for rehabilitation articles on Medline and Embase: An example with cross-over design. *Archives of Physical Medicine and Rehabilitation*, **81**, 720–722.

TASKS

1. Identify one professional area of interest.

2. Review one year of a journal from this area of interest for biomechanical articles.

3. Identify a potential biomechanical topic of interest from your professional interests.

4. Search a computer database (Medline or SportDiscus) for biomechanical papers on your topic.

5. Answer the questions.

LAB ACTIVITY 1   NAME _____

FINDING BIOMECHANICAL SOURCES

1. What is your professional area of interest, and give a human movement topic you have a biomechanical interest in?

2. Report the name of the journal, number of articles published in a particular year, and the percentage of articles related to biomechanics.

3. Summarize the results of two searches on a literature database like Medline or SportDiscus. Be sure to specify the exact search you used, and the number and quality of citations you obtained.

4. Based on all your searches, list the two citations you believe to be most relevant to your professional interests.

5. Comment on the diversity of sources you observed in your search.

6. Rate the quality of the sources you found based on the hierarchy of evidence presented in chapter.

LAB ACTIVITY 2

QUALITATIVE AND QUANTITATIVE ANALYSIS OF RANGE OF MOTION

This text summarizes many biomechanical variables and concepts into nine principles of biomechanics. The analysis of human movements using these biomechanical principles can be qualitative (subjective) or quantitative (based on numerical measurements). All kinesiology professions have used both qualitative and quantitative analyses of human movement, but qualitative analysis is used most often. This lab will explore the Range-of-Motion Principle of biomechanics, using a variety of static flexibility tests common in physical education and physical therapy. This lab will show you there are a variety of ways to quantify range of motion and that there are strengths and weaknesses of both qualitative and quantitative analyses of human movement.

Physical therapists used to perform a standing toe touch to screen for persons with limited hamstring flexibility. Patients either passed the test by being able to touch their toes with their fingers while keeping their legs straight, or they failed to touch their toes, indicating poor hamstring flexibility. Flexible hamstrings allows a person to tilt their pelvis forward more, making it easier to touch their toes. Recently, more accurate field tests of static flexibility have been developed. The tests that will be used are the sit-and-reach test (SRT), active knee extension (AKE), and the modified Schober test (MST). The results of these flexibility tests can be analyzed qualitatively (judging if the subject has adequate flexibility) or quantitatively. Quantitative analysis can either be norm-referenced (comparing scores to all other people) or criterion-referenced. Criterion-referenced testing compares test scores to some standard of what should be. Criteria or standards are usually based on evidence on what correlates with health (health-related fitness) or with physical abilities to perform jobs safely (occupational screening). For example, physical therapists studying the sit-and-reach test suggested that subjective observation of the forward tilt of the rear of the pelvis is as effective an assessment of hamstring flexibility as the SRT score (Cornbleet & Woolsey, 1996).

BACKGROUND READING

Chapter 2 herein: "Fundamentals of Biomechanics and Qualitative Analysis"

Cornbleet, S. & Woolsey, N. (1996). Assessment of hamstring muscle length in school-aged children using the sit-and-reach test and the inclinometer measure of hip joint angle. *Physical Therapy*, **76**, 850–855.

Gajdosik, R. & Lusin, G. (1983). Hamstring muscle tightness: Reliability of an active–knee-extension test. *Physical Therapy*, **63**, 1085-1088.

Gleim, G. W., & McHugh, M. P. (1997). Flexibility and its effects on sports injury and performance. *Sports Medicine*, **24**, 289–299.

Knudson, D., Magnusson, P., & McHugh, M. (2000, June). Current issues in flexibility fitness. *The President's Council on Physical Fitness and Sports Research Digest*, pp. 1-8.

TASKS

1. Select three volunteers for flexibility testing
2. Learn how to use a sit-and-reach box, inclinometer, goniometer, and tape measure for SRT, AKE, and MST.
3. Collect the following quantitative assessments of lumbar and hamstring range of motion for one side of the body: SRT, AKE, and MST. While these measurements are being taken, have people in your lab group do a qualitative/categorical assessment (hypoflexible, normal, hyperflexible) of the subject being tested.
4. Answer the questions.

LAB ACTIVITY 2   NAME _____

QUALITATIVE AND QUANTITATIVE ANALYSIS OF
RANGE OF MOTION

Ratings of Hamstring Flexibility

	Qualitative	SRT	AKE
Subject 1	_____	_____	_____
Subject 2	_____	_____	_____
Subject 3	_____	_____	_____

Ratings of Lumbar Flexibility

	Qualitative	Schober
Subject 1	_____	_____
Subject 2	_____	_____
Subject 3	_____	_____

1. Given that the healthy standard for adult (>17 years) males and females in the SRT are 17.5 and 20 cm, respectively, and a passing AKE is $\theta_K = 160°$, how well did your qualitative and quantitative ratings of hamstring flexibility agree?

2. Given that the passing score for the MST is 7 cm, how well did your qualitative and quantitative ratings of lumbar flexibility agree?

3. List the characteristics of the range of motion you evaluated in your qualitative ratings of hamstring flexibility.

4. Range of motion is a kinematic (descriptive) variable and does not provide kinetic (muscletendon resistance) information about the passive tension in stretching. Static flexibility measurements like these have been criticized for their subjectivity related to a person's tolerance for stretch discomfort (Gleim & McHugh, 1997). Are there kinetic aspects of stretching performance that can be qualitatively judged by your observations of these flexibility tests?

5. Compare and contrast the strengths and weaknesses of a qualitative versus quantitative assessment of static flexibility.

LAB ACTIVITY 3

FUNCTIONAL ANATOMY?

Anatomy is the study of the structure of the human body. The joint motions created by muscles in humans have been studied by anatomists several ways: cadaver dissection, and manipulation, observation, and palpation. Historically, anatomical analyses in kinesiology used the mechanical method of muscle action analysis to establish the agonists for specific movements. This requires a detailed knowledge of the planes of movement, joint axes, attachments, courses of the muscles, and the classification of joints. Anatomy provides only part of the prerequisite information necessary to determine how muscles create movement. A century of EMG research has clearly shown the inadequacy of functional anatomy to explain how muscles act to create human movement (Hellebrandt, 1963). Chapter 3 summarized several areas of research that show the integration of biomechanical research electromyography (EMG, kinetics, simulation) is necessary to understand the actions of muscles in human movement. This lab will review the mechanical method of muscle action analysis in functional anatomy and show why biomechanical analysis is needed to determine the actions of muscles.

BACKGROUND READING

Chapter 3 herein: "Anatomical Description and Its Limitations"

Hellebrandt, F. A. (1963). Living anatomy. *Quest*, **1**, 43–58.

Herbert, R., Moore, S., Moseley, A., Schurr, K., & Wales, A. (1993). Making inferences about muscles forces from clinical observations. *Australian Journal of Physiotherapy*, **39**, 195–202.

Maas, H., Baan, G. C., & Huijing, P. A. (2004). Muscle force is determined by muscle relative position: isolated effects. *Journal of Biomechanics*, **37**, 99-110.

TASKS

1. For the anatomical plane and joint(s) specified, use functional anatomy to hypothesize a muscle involved and the muscle action responsible for the following demos and record them on the lab report.

Demo 1 — Sagittal plane	elbow joint	arm curl
Demo 2 — Sagittal plane	lumbar vertebrae	trunk flexion
Demo 3 — Sagittal plane	metacarpophalangeal	passive wrist flexion
Demo 4 — Frontal plane	hip joint	left hip adduction

2. Perform the demos:

Demo 1: Lie supine with a small dumbbell in your right hand and slowly perform arm curls. Have your lab partner palpate your upper arm, being sure to note differences in muscle activation in the first 80 and last 80° of the range of motion. Analyze only the lifting phase.

Demo 2: Lie supine with your hips flexed to 90° and your quadriceps relaxed. Cross your arms over your chest and tighten your abdominal muscles. Make a note of which end of your body is elevated. See if you can make either or both sides of your body rise.

Demo 3: In the anatomical position, pronate your right forearm and flex your elbow completely. Totally relax your right hand and wrist. In this position (hand roughly horizontal), use your left hand to extend your relaxed right wrist and let gravity passively flex the wrist. Note the motion of the fingers during wrist extension and flexion.

Demo 4: From the anatomical position, stand on your left foot (flexing the right knee) and abduct your shoulders so that your arms are horizontal. Smoothly lower and raise your right hip (left hip adduction and then abduction) as many times as you can in one minute. Note the muscles that feel fatigued.

3. Answer the questions.

LAB ACTIVITY 3   NAME _____

FUNCTIONAL ANATOMY?

For the anatomical plane and joint(s) specified, use functional anatomy to hypothesize a muscle and the muscle action responsible for the following activities:

	Plane	Joint	Movement	Muscle	Action
Demo 1 —	Sagittal	elbow joint	arm curl	_____	_____
Demo 2 —	Sagittal	lumbar vertebrae	trunk flexion	_____	_____
Demo 3 —	Sagittal	metacarpophalangeal	wrist flexion	_____	_____
Demo 4 —	Frontal	hip joint	hip adduction	_____	_____

1. Functional anatomy does not consider the action of other forces (other muscles or external forces) in hypothesizing muscle actions. Describe the muscle actions throughout the range of motion in the horizontal plane arm curl, and note why an external force changes the muscle activation strategy.

2. Classifying muscle attachments as an "origin" or "insertion" is not always clear. What muscle(s) are active in the abdominal exercise, and what attachments are being pulled?

3. What muscle(s) created metacarpophalangeal extension when the wrist was passively flexed in Demo 3? What muscle(s) created metacarpophalangeal flexion when the wrist was passively extended? How does the muscle create this motion without activation?

4. Was there discomfort in the left hip adductors in Demo 4? What muscle and action was responsible for controlling left hip adduction?

5. Give a movement example (be specific) where functional anatomy may be incorrect because of:

   External forces

   Muscle synergy

   Passive tension

   Attachment stability changes

LAB ACTIVITY 4

MUSCLE ACTIONS AND THE STRETCH-SHORTENING CYCLE (SSC)

The forces muscles exert to create movement vary dramatically in terms of length, velocity of shortening or lengthening, and timing of activation. The classic *in vitro* muscle mechanical characteristics interact with other factors (activation, leverage, connective tissue stiffness, etc.) to determine the amount of torque a muscle group can create. The torque a muscle group creates naturally affects muscular strength, endurance, and other performance variables. The purpose of this lab is to demonstrate the performance consequence of muscle actions and the stretch-shortening cycle (SSC). The endurance of the elbow flexors will be examined in concentric and eccentric actions to review the Force–Velocity Relationship. Two kinds of vertical jumps will be examined to determine the functional consequences of the SSC.

BACKGROUND READING

Chapter 4 herein: "Mechanics of the Musculoskeletal System"

Komi, P. V. (Ed.) (1992). *Strength and power in sport*. New York: Blackwell Science.

Kubo, K., Kawakami, Y., & Fukunaga, T. (1999). Influence of elastic properties of tendon structures on jump performance in humans. *Journal of Applied Physiology*, **87**, 2090–2096.

Lieber, R., L., & Bodine-Fowler, S. (1993) Skeletal muscle mechanics: Implications for rehabilitation. *Physical Therapy*, **73**, 844–856.

TASKS

1. Select five volunteers for elbow flexor endurance testing. For each subject select a dumbbell with submaximal resistance (between 50 and 80% 1RM). Record the number or concentric-only repetitions (partners lower the dumbbell) for the person's stronger limb and the number or eccentric-only (partners lift the dumbbell) for their weaker limb. Attempt to keep a similar cadence for each test.

2. Perform and measure the maximum height for the countermovement jump (CMJ) and an equivalent static jump (SJ) for everyone in the lab. The SJ begins using isometric muscle actions to hold a squat position that matches the lowest point of the CMJ for that person. Observe jumps carefully since it is difficult to match starting positions, and it is difficult (unnatural) for subjects to begin the concentric phase of the SJ with virtually no countermovement.

3. Perform the calculations and answer the questions.

NAME _____

MUSCLE ACTIONS AND THE STRETCH-SHORTENING CYCLE (SSC)

Maximal Repetitions with a Submaximal Resistance

	Concentric—Stronger Side	Eccentric—Weaker Side
Subject 1	_____	_____
Subject 2	_____	_____
Subject 3	_____	_____
Subject 4	_____	_____
Subject 5	_____	_____

Pre-Stretch Augmentation in SSC

CMJ   _____   SJ   _____

$$PA (\%) = ((CMJ - SJ)/SJ) \cdot 100$$ (Kubo *et al.*, 1999)

My PA _____   Class Mean PA _____

QUESTIONS

1. Did the stronger side of the body have the most endurance? Explain the results of this comparison of concentric and eccentric muscles actions based on the Force–Velocity Relationship of muscle.

2. Hypothesize the likely lower extremity muscle actions in the SJ and the CMJ.

3. How much improvement in vertical jump could be attributed to using a SSC?

4. What aspects of coaching jumps and other explosive movements must be emphasized to maximize performance? Explain why your technique points may improve performance based on muscle mechanics or principles of biomechanics.

LAB ACTIVITY 5A

Velocity in Sprinting

Linear kinematics in biomechanics is used to create precise descriptions of human motion. It is important for teachers and coaches to be familiar with many kinematic variables (like speeds, pace, or times) that are representative of various levels of performance. Most importantly, professionals need to understand that velocity varies over time, as well as have an intuitive understanding of where peak velocities and accelerations occur in movement. This lab will focus on your own sprinting data in a 40-meter dash and a world-class 100-meter sprint performance to examine the relationship between displacement, velocity, and acceleration. These activities provide the simplest examples of linear kinematics since the body is modeled as a point mass and motion of the body is measured in one direction that does not change.

Background Reading

Chapter 5 herein: "Linear and Angular Kinematics"

Haneda, Y., *et al.* (2003). Changes in running velocity and kinetics of the lower limb joints in the 100m sprint running. Japanese *Journal of Biomechanics in Sports and Exercise*, **7**, 193-205.

Mero, A., Komi, P. V., & Gregor, R. J. (1992). Biomechanics of sprint running: A review. *Sports Medicine*, **13**, 376–392.

Murase, Y., *et al.* (1976). Analysis of the changes in progressive speed during the 100-meter dash. In P.V. Komi (Ed.), *Biomechanics V-B* (pp 200–207). Baltimore: University Park Press.

Tasks

1. Estimate how fast you can run in mph _____
2. Following a warm-up, perform a maximal 40-meter sprint. Obtain times with four stopwatches for times at the 10-, 20-, 30-, and 40-meter marks.
3. Perform the calculations and answer the questions.

Kinesiology Major Normative Data
Time (s)

	Females				Males			
	10	20	30	40	10	20	30	40
Mean	2.3	3.9	5.4	7.0	2.0	3.3	4.6	5.9
sd	0.2	0.4	0.5	0.7	0.2	0.2	0.3	0.5

Maurice Greene: 1999 World Championships Seville, Spain

Meters	Seconds
0–10	1.86
10–20	1.03
20–30	0.92
30–40	0.88
40–50	0.86
50–60	0.84
60–70	0.85
70–80	0.85
80–90	0.85
90–100	0.86
	9.67

LAB ACTIVITY 5A   NAME _____

VELOCITY IN SPRINTING

Record *your* times in the spaces below.

10 m	20 m	30 m	40 m
$t_1 =$ _____	$t_2 =$ _____	$t_3 =$ _____	$t_4 =$ _____

QUESTIONS

1. Calculate the average horizontal velocity in each of the 10-m intervals of your 40-m sprint (**V** = $\Delta\mathbf{d}/\Delta t$). Report your answers in m/s and mph (m/s · 2.237 = mph).

2. Calculate the average velocities for the intervals of Maurice Greene's 100-m sprint. Note that the times in the table represent the change in time (time to run the interval: Δt), not the cumulative time, as in your 40-m sprint data. Average velocities are usually assigned to the midpoints of the interval used for the calculation.

   Velocity (m/s) at the

   5____   15____   25____   35____   45____   55____   65____   75____   85____   95____

   meter points.

3. Plot Greene's and your velocities on the following velocity-displacement graph:

V
(m/s)

d (m)
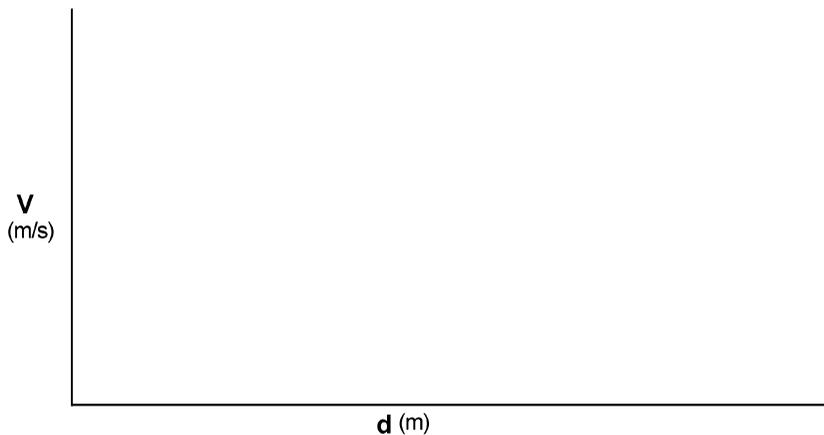
4. Give a qualitative description of the general slopes of the Greene velocity graph in question 3 (the general pattern would be same if this were a true velocity–time graph) that determine the acceleration phases of maximal sprinting. Where is acceleration the largest and why?

LAB ACTIVITY 5B

ACCURACY OF THROWING SPEED MEASUREMENTS

Linear kinematics in biomechanics are used to create precise descriptions of human motion. It is important for teachers and coaches to be familiar with many kinematic variables (like speeds, pace, or times) and the accuracy and consistency of these measurements. The accuracy of a speed calculated from the formula $s = l/t$ strongly depends on the time interval used and errors in measurement. The speed calculated is also an average over the time interval used for the calculation. The reliability of a measurement of speed decreases with greater variation from measurement errors and subject performance. This lab will allow you to explore accuracy and consistency issues in the measurement of ball speed in softball throwing.

BACKGROUND READING

Chapter 5 herein: "Linear and Angular Kinematics"

Atwater, A. E. (1979). Biomechanics of overarm throwing movements and of throwing injuries. *Exercise and Sport Sciences Reviews*, **7**, 75–80.

Brody, H. (1991, March/April). How to more effectively use radar guns. *TennisPro*, 4–5.

TASKS

1. Estimate how fast you can throw a softball: _____

2. Following a warm-up, perform maximal and 75% effort throws to a partner or chain link fence 20 m away. Measure and record the speed of the throws two ways: with a radar gun and by flight times averaged from four stopwatches. Be sure to note the variation in times measured by stopwatch operators, and record all time and radar data for all throws for everyone in the lab. Average speed of the throw will assume the distance of ball flight was 20 m.

3. Perform the calculations to calculate the average speed of your throws and answer the questions.

Kinesiology Major Normative Data for Maximum Effort Throws

	Females Speed (mph)	Males Speed (mph)
Mean	43.3	64.0
sd	8.6	8.7

LAB ACTIVITY 5B   NAME _____

ACCURACY OF THROWING SPEED MEASUREMENTS

Record *your* times in the spaces below.

          Maximal Throw   75% Effort Throw

    Speed = _____ t = _____   Speed = _____ t = _____

1. Calculate the average speed of your maximal and 75% effort throw ($s = \Delta l / \Delta t$) from the stopwatch data. Report your answers in m/s and mph (m/s ∗ 2.237 = mph). What factors would account for differences you observed between the radar and stopwatch measurements of ball speed?

2. Comment on the typical differences in stopwatch times for the four timers for maximal throws and 75% effort throws. About how accurate are stopwatches for estimating softball throwing speed?

3. Comment on how consistent were the radar measurements of your maximal and 75% effort throws. Given that reliability, how much of a difference would you consider meaningful?

4. Coaches sometimes ask athletes to perform warm-ups, drills, or practice at submaximal speeds. How effective were you and the persons in your lab at throwing at 75% of maximal speed?

LAB ACTIVITY 6A

TOP GUN KINETICS: FORCE–MOTION PRINCIPLE

Newton's laws of motion explain how forces create motion in objects. The application principle related to Newton's second law is the Force–Motion Principle. The purpose of this lab is improve your understanding of Newton's laws of motion. As a candidate for the prestigious "Top Gun" kinetic scooter pilot in biomechanics class, you must not only perform the missions but use kinetics to explain your scooter's flight. Biomechanics Top Gun is like a Naval Top Gun in that skill and knowledge are required to earn the honor. It is important that you follow the instructions for each mission explicitly. Care should be taken by pilots and their ground crew to perform the task correctly and safely. Note that your multimillion-dollar scooters provide *low* (not quite zero) friction conditions, so you need to move/push briskly so you can ignore the initial effects of friction. Kinetics explains all motion: from scooters, braces, rackets, jump shots, to muscle actions. Think about the forces, what directions they act, and the motion observed in each mission. This lab is roughly based on a lab developed by Larry Abraham (Abraham, 1991).

BACKGROUND READING

Chapter 6 herein: "Linear Kinetics"

Abraham, L. D. (1991). *Lab manual for KIN 326: Biomechanical analysis of movement*. Austin, TX.

TASKS

1. Using your multimillion-dollar scooters, ropes, and spring/bathroom scales, perform the following training missions:

— Sit on the scooter and maximally push off from a wall (afterburner check). Experiment with various body positions and techniques.

— Sit on your scooter and push off from a partner on another scooter.

— Loop a rope over a bathroom scale held by a partner on a scooter. Sit on your scooter and pull your partner, who passively holds the scale, and note the largest force exerted.

— Repeat the last mission, but have your partner also vigorously pull on the scale.

2. Answer the questions.

LAB ACTIVITY 6A   NAME _____

TOP GUN KINETICS: FORCE–MOTION PRINCIPLE

1. How far were you able to glide by pushing off from the wall? What is the relationship between the direction of your push and the direction of motion?

2. How far were you able to glide by pushing off from another scooter pilot? Explain any differences from task 1 using Newton's Laws of Motion.

3. How much force was applied to pull a passive partner? Which scooter pilot moved the most and why?

4. How much force was applied when both partners vigorously pulled on the rope? Explain any differences in the observed motion from task 3 using Newton's Laws.

5. Assume the mass of your scooter cannot be modified, but you are charged with recommending technique that maximizes scooter speed and agility. Use the Force–Motion Principle to suggest why a certain body position and propulsion technique is best.

LAB ACTIVITY 6B

IMPULSE–MOMENTUM: FORCE–TIME PRINCIPLE

The timing of force application to objects affects the stress and motion created. Newton's second law applied to forces acting over time is the impulse–momentum relationship. The change in momentum of an object is equal to the impulse of the resultant force. This activity will allow you to experience some interesting real-life examples of the impulse–momentum relationship. The purpose of this lab is to improve your understanding of changing the motion of an object (specifically, it's momentum) by applying force over a period of time. In some ways body tissues are similar to water balloons in that too much force can create stresses and strains that lead to injury. It is important for teachers/coaches to understand how movement technique affects the impulse and peak force that can be applied to an object. This lab is modified from a lab proposed by McGinnis and Abendroth-Smith (1991).

BACKGROUND READING

Chapter 6 herein: "Linear Kinetics"

McGinnis, P., & Abendroth-Smith, J. (1991). Impulse, momentum, and water balloons. In J. Wilkerson, E. Kreighbaum, & C. Tant, (Eds.), *Teaching kinesiology and biomechanics in sports* (pp. 135–138). Ames: Iowa State University.

Knudson, D. (2001c). Accuracy of predicted peak forces during the power drop exercise. In J. R. Blackwell (Ed.) *Proceedings of oral sessions: XIX international symposium on biomechanics in sports* (pp. 135–138). San Francisco: University of San Francisco.

TASKS

1. Estimate how far you can throw a softball-sized water balloon. _____

2. Estimate the maximum distance you could catch a similar water balloon. ____

3. Fill several water balloons to approximately softball size (≈7–10 cm in diameter).

4. Measure the maximal distance you can throw the water balloon. _____

5. Measure the maximal distance you and a partner can throw and catch a water balloon. _____

6. Answer the questions.

LAB ACTIVITY 6B   NAME _____

IMPULSE–MOMENTUM: FORCE–TIME PRINCIPLE

Distance of Throw _____   Distance of Toss & Catch _____

1. What technique factors were important in the best water balloon throws?

2. What technique factors were most important in successfully catching a water balloon?

3. Theoretically, if you could throw a water balloon 25 m, could you catch it? Why?

4. How are the mechanical behaviors of water balloons similar to muscles and tendons?

5. Below is a graph of the vertical force (**N**) measured when a medicine ball was dropped from the same height and bounced (●) or was caught and thrown back up in a power drop exercise (◆). Use the Force–Time Principle to explain the differences in the forces applied to the medicine ball. Data from Knudson (2001c).
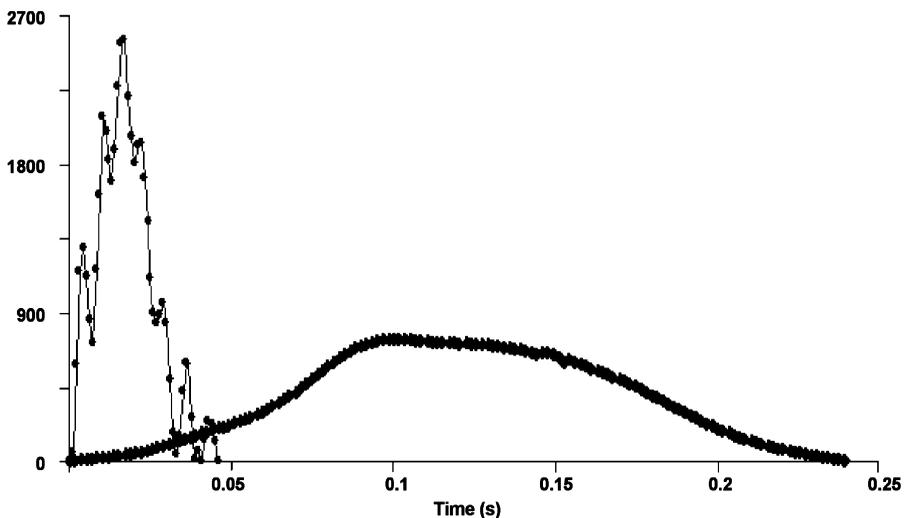
LAB ACTIVITY 7A

ANGULAR KINETICS OF EXERCISE

The positions of body segments relative to gravity determine the gravitational torques that must be balanced by the muscles of the body. The purpose of this lab is to improve your understanding of torque, summation of torques, lifting, and center of gravity. These biomechanical parameters are extremely powerful in explaining the causes of human movement because of the angular motions of joints. Several classic lifting and exercise body positions are analyzed because the slow motion (very small or zero acceleration) in these movements comprise a quasi-static condition. In static conditions, Newton's second law can be simplified to static equilibrium: $\Sigma\mathbf{F} = 0$ and $\Sigma\mathbf{T} = 0$. Remember that a torque ($\mathbf{T}$) or moment of force is the product of the force and the perpendicular distance between the line of action of the force and the axis of rotation ($\mathbf{T} = \mathbf{F} \cdot \mathbf{d}_\perp$).

BACKGROUND READING

Chapter 7: "Angular Kinetics"

Chaffin, B. D., Andersson, G. B. J., & Martin, B. J. (1999). *Occupational biomechanics* (3rd ed.). New York: Wiley.

Hay, J. G., Andrews, J. G., Vaughan, C. L., & Ueya, K. (1983). Load, speed and equipment effects in strength-training exercises. In H. Matsui & K. Kobayashi (Eds.), *Biomechanics III-B* (pp. 939–950). Champaign, IL: Human Kinetics.

van Dieen, J. H., Hoozemans, M. J. M., & Toussaint, H. M. (1999). Stoop or squat: A review of biomechanical studies on lifting technique. *Clinical Biomechanics*, **14**, 685–696.

TASKS

1. If an athlete doubled his/her trunk lean in a squat exercise, how much more resistance would their back feel? Estimate the extra load on the lower back if a person performed a squat with a 40° trunk lean compared to a 20° trunk lean. _____ %

2. Obtain height, weight, and trunk length (greater trochanter to shoulder joint) data for a person in the lab.

3. The amount of trunk lean primarily determines the stress placed on the back and hip extensors (Hay *et al.*, 1983). Perform two short endurance tests to see how trunk lean affects muscle fatigue. Use a standard bodyweight squat technique. Hold the squats with hands on hips in an isometric position for 30 seconds and subjectively determine which muscle groups were stressed the most. Test 1 is a squat with a nearly vertical trunk and a knee angle of approximately 120°. Test 2 is a squat with a trunk lean of about 45° and a knee angle of approximately 120°. Wait at least 5 minutes between tests.

4. Perform calculations on the following simple free-body diagrams of exercise and body positions to examine how gravitational torques vary across body configurations and answer the questions.

LAB ACTIVITY 7A   NAME _____

ANGULAR KINETICS OF EXERCISE

1. Where were the sites of most fatigue in the two squat tests? What muscle group feels more fatigue in a nearly vertical trunk orientation? Why?

2. Kinematic measurements from film/video and anthropometric data are often combined to make angular kinetic calculations. A static analysis can be done when the inertial forces and torques (dynamic loading from high-speed movement) are small. Assume the figure below is an image of you captured from video while performing bodyweight squats. Calculate a gravitational torque of *your* upper body about the hip (M/L) axis. Assume your head, arms, and trunk (HAT) have mass equal to 0.679 of body mass. The center of gravity of your HAT acts at 62.6% up from the hip to the shoulder.

3. Calculate the gravitational torque about the hip if the bottom of your squat exercise has a trunk lean of 40°. (Show free-body diagram and work.)

4. If the weight of the head, arms, and trunk do not change during the squat exercise, what does change that increases gravitational torque as the person leans forward?

5. How different is the load on the back/hip extensors when you double your trunk lean? Is the size of this difference what you expected? Why is it different?

LAB ACTIVITY 7B

CALCULATING CENTER OF GRAVITY USING ANGULAR KINETICS

The purpose of this lab is to improve your understanding of torque, summation of torques, and center of gravity. Torque is a useful kinetic variable explaining the causes of human movement because of the angular motions of joints. Locating the center of gravity of an object and tracking its motion is useful in understanding how the force of gravity affects movement and balance. The reaction board method will be used with the angular analog and static form of Newton's second law ($\Sigma \mathbf{T} = 0$). Remember that torque ($\mathbf{T}$) or moment of force is the product of the force and the perpendicular distance between the line of action of the force and the axis of rotation ($\mathbf{T} = \mathbf{F} \bullet \mathbf{d}_\perp$).

BACKGROUND READING

Chapter 7: "Angular Kinetics"

Gard, S. A., Miff, S. C, & Kuo, A. D. (2004). Comparison of kinematic and kinetics methods for computing the vertical motion of the body center of mass during walking. *Human Movement Science*, **22**, 597–610.

TASKS

1. Estimate the height of your center of gravity as a percentage of your height: _____.

2. Record your height and weight. Measure the length of the reaction board from one supporting edge to the other.

3. Measure the reaction force lying on the reaction board in your normal standing position, and in another sport/activity relevant position of interest to you. Think about where you should you put your feet to make the calculation easier to express relative to your body.

4. Perform calculations to calculate the location of your center of gravity and answer the questions.

LAB ACTIVITY 7B   NAME _____

ANGULAR KINETICS OF EXERCISE

Record your data in the space below:

 Height _____   Weight _____   Reaction standing _____   Reaction other _____

1. Draw a free body diagram of you on the reaction board and calculate the location of your center of gravity.

2. Calculate the height of your center of gravity as a percentage of your height and discuss any differences from normative data for your gender.

3. Calculate the location of your center of gravity in the other body position (show free body diagram and work).

4. Explain the difference in the center of gravity location between the two body postures you studied, and how it might affect stability and mobility.

LAB ACTIVITY 8

MAGNUS EFFECT IN BASEBALL PITCHING

Fluid forces have dramatic effects in many human movements. Fluid dynamics is of vital interest to coaches of swimming, cycling, running, and sports where wind or ball velocities are great. The fluid forces of lift and drag increase with the square of velocity. The purpose of this lab is to improve your understanding of how fluid forces (specifically lift) can be used to affect a thrown balls trajectory. The example is in baseball pitching, although the Spin Principle applies to other ball sports. Pitching technique and the Magnus Effect are explored in the "rise" of a fastball, the "break" of a slider, and the "drop" of a curveball. Skilled performance in many sports involves appropriate application of rotation to a ball to create fluid forces for an advantageous trajectory.

BACKGROUND READING

Chapter 8 herein: "Fluid Mechanics"

Allman, W. F. (1984). Pitching rainbows: The untold physics of the curve ball. In E. W. Schrier & W. F. Allman (Eds.), *Newton at the bat: The science in sports* (pp. 3–14). New York: Charles Scribner & Sons.

Knudson, D. (1997). The Magnus Effect in baseball pitching. In J. Wilkerson, K. Ludwig, & M. Butcher (Eds.), *Proceedings of the 4th national symposium on teaching biomechanics* (pp. 121–125). Denton: Texas Woman's University Press.

TASKS

1. Set up a mock baseball pitching situation indoors with a pitching rubber and home plate about 7 m apart. Warm up the shoulder and arm muscles and gradually increase throwing intensity with whiffle balls. Exchange the whiffle ball for a styrofoam ball.

2. Hitters often perceive that a well-thrown fastball "rises" (seems to jump over their bat). The fastball is usually thrown with the index and middle fingers spread and laid across the seams of a ball, with the thumb providing opposition from the front of the ball. At release, the normal wrist flexion and radioulnar pronation of the throwing motion create downward and forward finger pressure on the ball. These finger forces create backspin on the ball. Try to increase the rate of backspin to determine if the ball will rise or just drop less than a similar pitch. Be careful to control the initial direction of the pitches by using visual references in the background. Estimate the rise or drop of the pitch relative to the initial trajectory at release.

3. A pitch that is easy to learn after the basic fastball is a slider. A slider creates a lateral "break" that can be toward or away from a batter, depending on the handedness of the pitcher and batter. The grip for a slider (right-handed pitcher) has the index and middle finger together and shifted to the right side of the ball (rear view). The thumb provides opposition from the left side of the ball. Normal wrist flexion and pronation at release now create a final push to the right side of the ball, imparting a sidespin rotation. A typical right-handed pitcher (facing a right-handed hitter) would usually direct this pitch initially toward the center to the outside corner of home plate, so the ball would break out of reach.

4. A pitch that can make a batter look foolish is the curveball. The common perception of hitters watching a well-thrown curveball is that the ball seems to "drop off the table." The ball looks like it is rolling along a horizontal table toward you and suddenly drops off the edge. The grip for a curveball is similar to a fastball grip, but with a different orientation of the seams. At release the index and middle fingers are on top of the ball, making a final push forward and downward. Common teaching cues are to pull down at release like pulling down a shade or snapping your fingers. Research has shown that radioulnar pronation is delayed in the curveball, so that at release the forearm is still in a slightly supinated position. Curveballs are thrown with forearm pronation just like other pitches; it is just delayed to near the moment of release.

5. If time is available, students can do some "show and tell" with other pitch variations. These include variations in release (sidearm, windmill softball pitch, grips, screwball, knuckleball, etc.).

6. Answer the questions.

LAB ACTIVITY 8   NAME _____

MAGNUS EFFECT IN BASEBALL PITCHING

1. Were you able to make a styrofoam fastball rise? Draw a free-body diagram of your fastball, showing all relevant forces and explain how it relates to the vertical motion of the ball you observed.

2. Could you make a styrofoam slider break sideways? If so, how much?

3. Draw a rear view of the ball from the pitcher's (your) perspective and draw on the ball the axis of ball rotation and Magnus force for your slider.

4. Draw a rear view of the ball from the pitcher's (your) perspective and draw on the ball the axis of ball rotation and Magnus force for your curveball. In what direction(s) did your curveball break?

5. Did your curveball have more lateral or downward break? Why?

6. To get a ball to curve or break to the right with the Spin Principle, describe how force is applied to the ball? Would this be the same for curves to the right in other impact and release sports?

LAB ACTIVITY 9

QUALITATIVE ANALYSIS OF LEAD-UP ACTIVITIES

An effective teaching strategy for many sports skills is to provide a sequence of lead-up activities that are similar to and build up to the skill of interest. How biomechanically similar the lead-up activities are to the sport skill of interest is important to physical educators. A qualitative answer to the similarity question will be explored in a sport skill selected by the instructor. The present lab will allow you to practice qualitative analysis of human movements using the biomechanical principles.

BACKGROUND READING

Chapter 9 herein: "Applying Biomechanics in Physical Education"

Knudson, D. V., & Morrison, C. S. (2002). *Qualitative analysis of human movement* (2nd ed.). Champaign, IL: Human Kinetics.

TASKS

1. For the sport skill identified by the instructor, identify two lead-up skills, activities, or drills.

2. Select a volunteer to perform these movements.

3. Videotape several repetitions of the movements from several angles.

4. Observe and evaluate the performance of the biomechanical principles in each movement using videotape replay.

5. Answer the questions.

LAB ACTIVITY 9   Name _____

Qualitative Analysis of Lead-Up Activities

1. What biomechanical principles are most relevant to the sport skill of interest?

2. What was the first lead-up movement? What biomechanical principles are related to performance of this lead-up movement?

3. What was the second lead-up movement? What biomechanical principles are related to performance of this lead-up movement?

4. For the volunteer in your lab, what lead-up movement was most sport-specific? What biomechanical principles were most similar to the sport skill?

LAB ACTIVITY 10

COMPARISON OF SKILLED AND NOVICE PERFORMANCE

Coaching strives to maximize the performance of an athlete or team in competition. A key ingredient of athletic success is motor skill. Most aspects of skill are related to the biomechanical principles of human movement. A good way to practice the qualitative analysis of sport skills is to compare the application of biomechanical principles of a novice and those of a skilled performer. The purpose of this lab is to compare the application of biomechanical principles in a skilled performer and a novice performer in a common sport skill.

BACKGROUND READING

Chapter 10 herein: "Applying Biomechanics in Coaching"

Hay, J. G. (1993). *The biomechanics of sports techniques* (4th. ed.). Englewood Cliffs, NJ: Prentice-Hall.

Knudson, D. V., & Morrison, C. S. (2002). *Qualitative analysis of human movement* (2nd ed.). Champaign, IL: Human Kinetics.

TASKS

1. Select a sport skill where a novice and a skilled performer can be found from students in the lab.

2. Select two volunteers (one novice and one skilled) to perform the skill.

3. Videotape several repetitions of the skill from several angles

4. Observe and evaluate performance of the biomechanical principles in each movement using videotape replay.

5. Answer the questions.

NAME _____

COMPARISON OF SKILLED AND NOVICE PERFORMANCE

1. What are the biomechanical principles most relevant to the sport skill of interest?

2. What biomechanical principles are strengths and weaknesses for the novice performer?

3. What biomechanical principles are strengths and weaknesses for the skilled performer?

4. What intervention would you recommend for the novice performer and why?

5. What intervention would you recommend for the skilled performer and why?

LAB ACTIVITY 11

COMPARISON OF TRAINING MODES

Strength and conditioning coaches prescribe exercises to improve performance based on the Principle of Specificity. This is often called the "SAID" principle: Specific Adaptation to Imposed Demands. There are a variety of free-weight, elastic, and mechanical resistances that coaches can prescribe to train the neuromuscular system. Qualitative analysis of exercise technique based on biomechanical principles can help a strength coach make two important evaluations: is the exercise technique safe and is it sport-specific? This lab will focus on the latter. The purpose of this lab is to compare the specificity of exercise technique in training for a sport skill.

BACKGROUND READING

Chapter 11 herein: "Applying Biomechanics in Strength and Conditioning"

Knudson, D. V., & Morrison, C. S. (2002). *Qualitative analysis of human movement* (2nd ed.). Champaign, IL: Human Kinetics.

TASKS

1. Select a sport skill of interest.

2. Select three exercises that will train the main agonists for the propulsive phase of the skill. Be sure to select an elastic resistance, inertial resistance (free weight), and an exercise machine. Strive to make the resistances about equal in these exercises.

3. Select a volunteer to perform the exercises.

4. Videotape several repetitions of the exercises perpendicular to the primary plane of movement.

5. Observe and evaluate the performance of the biomechanical principles in each exercise using videotape replay.

6. Answer the questions.

NAME _____

COMPARISON OF TRAINING MODES

1. What are the biomechanical principles most relevant to the sport skill of interest?

2. What was the first exercise? What biomechanical principles of this exercise are similar to the sport skill?

3. What was the second exercise? What biomechanical principles of this exercise are similar to the sport skill?

4. What was the third exercise? What biomechanical principles of this exercise are similar to the sport skill?

5. Which exercise was most sport-specific? Why? (Be sure to explain based on the importance of certain biomechanical principles in terms of performance in the sport.)

LAB ACTIVITY 12

QUALITATIVE ANALYSIS OF WALKING GAIT

Sports medicine professionals qualitatively analyze movement to find clues to injury and to monitor recovery from injury. Walking is a well-learned movement that athletic trainers, physical therapists, and physicians all qualitatively analyze to evaluate lower-extremity function. There is a variety of qualitative and quantitative systems of gait analysis. This lab will focus on the qualitative analysis of two walking gaits based on biomechanical principles. Professionals qualitatively analyzing gait must remember that quantitative biomechanical analyses are needed in order to correctly estimate the loads in musculoskeletal structures, so assumptions about muscle actions in gait from body positioning alone are unwise (Herbert *et al.*, 1993).

BACKGROUND READING

Chapter 12 herein: "Applying Biomechanics in Sports Medicine and Rehabilitation"

Herbert, R., Moore, S., Moseley, A., Schurr, K., & Wales, A. (1993). Making inferences about muscles forces from clinical observations. *Australian Journal of Physiotherapy*, **39**, 195–202.

Knudson, D. V., & Morrison, C. S. (2002). *Qualitative analysis of human movement* (2nd ed.). Champaign, IL: Human Kinetics.

Whittle, M. (1996). *Gait analysis: An introduction* (2nd ed.). Oxford: Butterworth-Heinemann.

TASKS

1. Select a volunteer to perform the walking trials.

2. Have the volunteer walk in three conditions: their natural gait, as fast as they comfortably can, and simulating an injury. Injury can be easily simulated by restricting joint motion with athletic tape or a brace. Antalgic (painful) gait can be simulated by placing a small stone in a shoe.

3. Videotape several cycles of each waking gait.

4. Observe and evaluate performance related to the biomechanical principles in each gait using videotape replay.

5. Answer the questions.

LAB ACTIVITY 12   NAME _____

QUALITATIVE ANALYSIS OF WALKING GAIT

1. What biomechanical principles are most evident in natural walking gait?

2. What biomechanical principles increased or decreased in importance relative to normal gait, during fast gait?

3. What injury did you simulate? What biomechanical principles increased or decreased in importance relative to normal gait, during injured gait?

4. What musculoskeletal structures are affected in your simulated injury? Hypothesize the likely changes in muscular actions and kinematics because of this injury and note where you might find biomechanical literature to confirm your diagnosis.