

ME 4670 / 5670

Engineering Biomechanics of Human Motion



**Laboratory Exercises
Spring 2024**

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These laboratory exercises were adapted from the laboratory manual associated with:

N. Hamilton, W. Weimar, and K. Luttgens, 2008, [Kinesiology: Scientific Basis of Human Motion](#), 11th edition, McGraw-Hill, Boston, MA.

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Laboratory Report Format

This section presents the **required** report format for the ME 4670 / 5670 laboratories all semester. From previous experience I have found that most student teams can do the laboratories and get reasonable results easily enough. In order to obtain the best grade possible on each laboratory, you should focus on clear, complete, technical report writing with extra effort. **Include plenty of clear sketches, graphics, and digital photos and good discussion on all points.** In addition, include overall Discussion and Conclusion sections for all lab reports.

Feel free to use graphics from any valid source, but you **MUST** acknowledge the source in your report (where it appears in your report AND in the report bibliography). Complete website references are valid.

One report is to be submitted for each lab for each lab team (2-3 students).

MEMO (serves as the Abstract) – first page, no cover sheet necessary

1. Objectives

2. Background

3. Results

4. Discussion

5. Conclusion

Bibliography

Appendices (as necessary)

Significant Figures

Significant figures (abbreviated sig figs or s.f.) are important in any branch of science and engineering involving numerical calculations. It is my observation that with the advent and mainstream use of digital calculators and computers, many students, faculty, and engineers have lost sight of the important concept of significant figures. Please pay attention to significant figures in all Biomechanics of Human Motion laboratories this semester – indeed, in all of your engineering work in the future.

The amount of significant figures in any number is the amount of digits with meaning. This is related to the precision of a number or measurement, which is the degree of closeness a number is reported to. In calculations involving multiple numbers, the amount of significant figures in the result must be equal to that of the least significant number that enters the calculations.

One cannot report more digits in a measurement than is warranted by the measuring device. For instance, in a protractor marked to the nearest 1 degree, I was taught that you can report results to the nearest $\frac{1}{2}$ degree, but the result is significant only to the nearest degree.

Significant Figures Rules

- all non-zero digits are significant
15 has two sig figs and 5.4321 has five sig figs
- leading zeros or trailing zeros are not significant unless otherwise stated
0.15 has two sig figs, 0.00015 also has two sig figs, and 200 has one sig fig

exceptions:
200. has three sig figs, 200 has two sig figs, and 200 has three sig figs
- trailing zeros after the decimal point are significant
0.000150 has three sig figs and 0.00015000 has five sig figs
- intermediate zeros are significant
101 has three sig figs and 202.408 has six sig figs
- scientific notation has the same rules
 1.5×10^{-4} has two sig figs and 1.5000×10^{-4} has five sig figs

Lab 1. Vectors

Objectives

- Define key biomechanical measurement terms and state how each relates to the structure of biomechanics study.
- Convert the units of measurement employed in the study of biomechanics from the U.S. system to the metric system, and vice versa.
- Demonstrate the use of the graphic method for the combination and resolution of two-dimensional vectors.
- Demonstrate the use of the trigonometric method for the combination and resolution of two-dimensional vectors.
- Identify the scalar and vector quantities represented in individual motor skills and describe the vector quantities using vector diagrams.

Background

The units of measurement employed in the study of biomechanics are expressed in terms of space, time, and mass. Presently in the United States, there are two systems of measurement having units for these quantities, the U.S. system and the metric system. Although the metric system is currently used in research and literature, a comparison of equivalent values is helpful.

Quantities that are used in the description of motion may be classified as either scalar or vector in nature. Scalar quantities are single quantities. They possess only size or amount. This size or amount is referred to as magnitude and completely describes the scalar quantity. The units of measure described in the previous section are primarily scalar quantities, described only by magnitude. Examples of scalar quantities would be such things as a speed of 8 kilometers per hour, a temperature of 70 degrees, an area of 2 square kilometers, a mass of 10 kilograms, or a height of 2 meters.

There are also double quantities that cannot be described by magnitude alone. These double quantities are called vector quantities. A vector quantity is described by both magnitude and direction. Examples of vector quantities would be a velocity of 8 kilometers per hour in a northwest direction, 10 Newtons of force applied at a 30-degree angle, a displacement of 100 meters from the starting point. The importance of clearly designating vector quantities can be seen if the direction component of the double quantity is altered. For instance, if two people on opposite sides of a door push with equal magnitudes (amounts) of force, the door will not move. If, on the other hand, they both push on the same side of the door, thus changing the direction of one of the forces, the result will be very different. The nature of the movement of the door depends upon both the amount and direction of the force. Force, therefore, is a vector quantity. If the individual who ran 8 kilometers runs 8 more kilometers, the total distance run will be 16 kilometers. However, if the runner goes 8 kilometers in one direction, reverses, and runs back to the starting point, the change in position or displacement is zero. The runner is zero kilometers from the starting point. Displacement, then, is also a vector quantity possessing both magnitude and direction. Numerous quantities in biomechanics are vector quantities. In addition to force, displacement, and velocity already mentioned, some other examples are momentum, acceleration, friction, work, and power. Vector quantities exist whenever direction and amount are inherent characteristics of the quantities.

A vector is represented by an arrow whose length is proportional to the magnitude of the vector. The direction in which the arrow points indicates the direction of the vector quantity. Vector quantities are equal if magnitude and direction are the same for each vector. Although all the vectors below are of the same length (magnitude) only two are equal vector quantities.

Vectors may be combined by addition, subtraction, or multiplication. They are added by joining the head of one with the tail of the next while accounting for magnitude and direction. The combination results in a new vector called the resultant. The resultant vector is represented by the distance between the last head and the first tail.

The subtraction of vectors is done by changing the sign of one vector (multiply by -1) and then adding as before. The multiplication of a vector by a number changes its magnitude only, not its direction.

As just explained, the combination of two or more vectors results in a new vector. Conversely, any vector may be broken down or resolved into two component vectors acting at right angles to each other. Should one wish to know how much of a velocity was in a horizontal direction and how much in a vertical direction, for instance, the resultant vector (R) must be resolved into horizontal and vertical components. The vector addition of these components once again would result in the resultant vector R.

Any vector may be resolved into horizontal and vertical components if the trigonometric relationships of a right triangle are employed. Let us use the example of the jumper whose velocity at takeoff was 9.6 meter/sec in the direction of 18 degrees with the horizontal. To find the horizontal velocity (V_x) and vertical velocity (V_y) at takeoff a right triangle is constructed. With the takeoff velocity (R) as the hypotenuse of the triangle, the vertical and horizontal components of velocity become the vertical and horizontal sides of the triangle. To obtain the values of V_x and V_y the sine and cosine functions are used. The horizontal velocity of the jump V_x turns out to be 9.1 m/s.

The combination of vectors is also possible with the use of right triangle trigonometric relationships. If two vectors are applied at right angles to each other the solution should appear reasonably obvious since it is the reverse of the example just explained. If a baseball is thrown with a vertical velocity of 15 meter/sec and a horizontal velocity of 26 meter/sec the velocity of the throw and the angle of release may be determined by using the Pythagorean Theorem to find the magnitude of the resultant vector and using the tangent function (\tan^{-1}) to find the appropriate angle. The resultant velocity--that is, the velocity of the throw--is 30 meter/sec and the angle of projection is 30 degrees.

If more than two vectors are involved or if they are not at right angles to each other as shown in previous examples, the resultant may be obtained by determining the x and y components for each individual vector and then summing these individual components to obtain the x and y components of the resultant. Once the x and y components are known, the magnitude and direction of R may be obtained.

As we have seen before, a knowledge of the horizontal (x) and vertical (y) components makes it possible to determine the resultant vector. A triangle is formed and the unknown parts are found.

Sig Figs

For this report only, assume you have sufficient precision in each number to report all results to the nearest **tenth decimal place**.

Lab 1 Report – Vectors

Name(s) _____

Date _____

1. Define the following key terms in your own words.

kinematics

statics

dynamics

scalar

vector

2. Express the following terms in SI units.

a. a force of 25 pounds

b. a mass of 5 slugs

c. a distance of 11 inches

d. a velocity of 20 feet per second

e. a volume of 3 quarts

3. Determine the distance and angle (polar notation) between each set of points. Draw a vector diagram to scale for each case.

a. $(2,3); (5,7)$

b. $(1,2); (3,3)$

c. $(1.5,3.0); (6,6)$

d. $(0,0); (6.2, 3.6)$

4. Find the x and y components for each of the following vectors. Draw a vector diagram to approximate scale for each case. Unless otherwise specified (see #9 orienteering later) in this course, always measure angles with the right hand from the positive horizontal.

a. 45 m at 25°

b. 85 m/sec at 135°

c. 118 m/sec² at 210°

d. 225 N at 310°

5. A basketball official runs 20 meters along the sideline in one direction, reverses, and runs 8 meters.

Draw the vector diagram.

What is the distance run?

What is the displacement?

6. The force of a muscle is 650 N, pulling on a bone at an angle of 15 degrees. Draw the diagram (assume the bone is horizontal). What are the horizontal and vertical components of this force?

7. At the moment of release, a baseball has a horizontal velocity component of 25 meters per second and a vertical velocity component of 14 meters per second. Draw the diagram.

At what angle was it released?

What was its initial velocity in the direction of the throw in meters/sec?

8. A child is being pulled in a sled by a person holding a rope that has an angle of 20 degrees with the horizontal. The total force being used to move the sled at a constant forward speed is 110 N. Draw the diagram.

How much of the force is horizontal?

How much of the force is vertical?

9. An orienteer runs the following course: 1000 meters at 45° ; 1500 meters at 120° ; 500 meters at 190° . Assume all angles are measured in an absolute manner (not relative to the previous leg), left-handed with respect to the positive vertical direction (true north is the standard reference in orienteering). **Note compass readings are left-handed: N 0° , E 90° , S 180° , and W 270° .**

a. Draw the course to scale accurately on a separate piece of paper.

b. Determine the resultant displacement graphically from a.

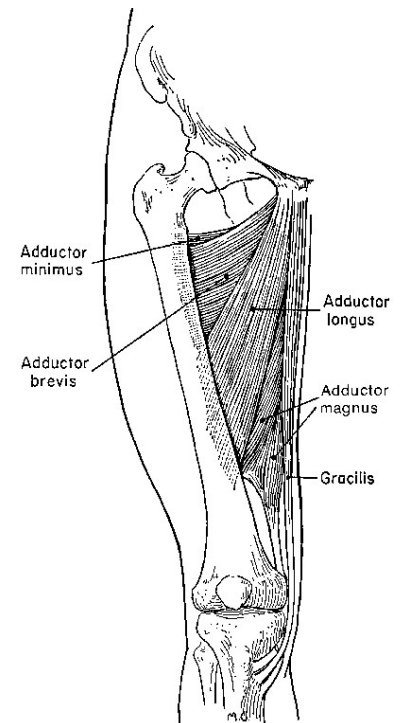
c. Determine the resultant displacement trigonometrically.

d. Express the orienteer's position at the end of the course in terms of rectangular coordinates and also in terms of polar coordinates.

e. Explain any differences between your graphic and trigonometric results.

10. A football lineman charges an opponent with a force of 175 pounds in the direction of 310° . The opponent charges back with a force of 185 pounds in the direction of 90° . Draw the vector diagram. What is the resultant force and in what direction will it act? This problem should be interpreted in the top view, with forces in the horizontal plane.

11. Refer to the drawing of the femur and adductor longus muscle. Draw a straight line to represent the main long mechanical axis of the femur and another to represent the muscle's effective line of pull.



a. Using a protractor, determine the angle of pull of the muscle (angle formed by muscle's line of pull and mechanical axis of bone – this is called the **angle of pennation**). Clearly show your measurement in the diagram above.

b. Assuming a total muscle force of 900 N, calculate the *XY* force components. Clearly show your *XY* reference axes in the diagram above.

12. Muscle A has a force of 450 N and is pulling on a bone at an angle of 15 degrees. Muscle B has a force of 600 N and is pulling on the same bone at the same spot but at an angle of 30 degrees. Muscle C has a force of 325 N and is pulling at the same spot with an angle of pull of 10 degrees. All angles should be measured with the right hand from the absolute horizontal. Draw the vector diagram. What is the composite effect of these muscles in terms of amount of force and direction? (i.e. find the resultant force using vector addition, and report it in polar coordinates.)

Lab 2. Kinetics

Objectives

- State Newton's laws as they apply to both linear and rotary motion.
- Explain the cause and effect relationship between the forces responsible for linear motion and the objects experiencing the motion.
- Explain the cause and effect relationship between the forces responsible for rotary motion and the objects experiencing the motion.
- Explain the analogous kinetic relationships that exist between linear and rotary motion.

Background

There is a relationship between linear and angular kinematics based on the length of the radius of a lever. The greater the distance from the axis to a point the greater will be the displacement of the point and the derivatives of displacement.

Newton's three laws govern motion in this universe. These three laws are:

1. Law of Inertia – a body at rest will remain at rest and a body in motion will remain in motion until acted upon by an outside force.
2. Law of Acceleration – acceleration of a body is directly proportional to force and indirectly proportional to mass ($F = ma$).
3. Law of Reaction – for every action there is an equal and opposite reaction.

The quantity of motion that an object possesses is referred to as momentum. Momentum is a product of mass and velocity (mv). Since a change in velocity is an acceleration and since acceleration requires the application of a force over some period of time, it requires a force over a period of time to change momentum. This is called impulse (Ft). Momentum within a system, once established, remains constant until an impulse is applied.

When two objects collide the total momentum of the system will be the sum of the momentums imparted by each object.

Equipment

Two balls of unequal mass
 Push stick
 Smoothly rotating chair or platform
 Block of wood
 Plastic bat, batting tee, indoor ball
 Weighted bags

Note: if you are lacking some of these items, **DO NOT go shopping**. Instead substitute what you have handy and clearly report what you used and what the results were. If adequate substitutes are not freely available, you and your partner can instead use thought experiments with virtual equipment to satisfy the requirements in those sections – at no penalty.

Lab 2 Report – Kinetics

Name(s) _____

Date _____

Experiment 1

Equipment: two balls of unequal mass (e.g. golf ball and table tennis ball), push stick

1. Place the two balls against the stick. Applying even force along the length of the stick, push the two balls approximately 10 cm. Stop the stick suddenly and observe the action of the balls.

Draw the motion diagram including all important parameters.

What type(s) of motion did you observe?

In what way did the balls exhibit the motion(s) observed?

Which ball travels farther?

Give a mechanical reason for this result.

2. Repeat the experiment, using the same force, but push for approximately 20 cm.

In which of the two trials did the balls travel farther?

Give a mechanical reason for this difference.

Experiment 2

Equipment: rotating platform or chair

1. Have a subject sit on the rotating platform or chair in such a way that no part of the body is in contact with the floor. Start the platform or chair spinning. As the platform or chair spins, have the subject suddenly abduct the arms.

Draw the motion diagram including all important parameters.

What happens to the rotation when the arms are abducted?

Give a mechanical reason for your results.

2. Repeat the experiment. Immediately following the abduction of the arms have the subject quickly adduct again, bringing the arms in close to the body.

What happens to the rotation in this case?

Give a mechanical explanation for your results.

3. Have the subject attempt to start the platform rotating, with no contact on any external surface by either the arms/hands or the legs/feet.

Is the subject successful in this attempt?

Give a mechanical explanation for this success or failure.

Experiment 3

Equipment: wooden block, notebook

1. Put the block on top of the notebook that is flat on the floor. Quickly jerk the notebook towards you.

Draw the motion diagram including all important parameters.

What happens to the block?

Give a mechanical reason for this result.

2. Now pull the notebook towards you slowly.

What happens to the block?

Give a mechanical reason for this result.

3. Now pull the notebook towards you smoothly but rapidly. Stop the notebook abruptly.

What happens to the block?

Give a mechanical reason for this result.

Experiment 4

Equipment: plastic bat, batting tee, indoor ball

With the bat, hit the ball from the tee and mark its landing point. Next, toss the ball up to yourself, hit it, and mark the landing point. Finally, hit a ball that is pitched to you and mark the landing point. Use a consistent swing speed throughout the experiment.

Draw the motion diagram including all important parameters.

Under which condition did the ball travel the furthest? The second and third furthest?

Give a mechanical reason for these results.

Experiment 5

Equipment: weighted bags

Perform a standing long jump under each of the following conditions. Mark the distance jumped for each condition. Draw the motion diagrams including all important parameters.

- a. Using no arm motion.
- b. Using a swinging motion of the arms.
- c. Same as b while holding a weight in each hand.
- d. Same as c plus swing the weights forward as you jump. At the peak of the jump throw the weights down and backward. This one may require some practice.

Rank the four jump conditions from longest to shortest.

Give at least 2 mechanical reasons for these results.

Lab 3. Range Of Motion

Objectives

- Name the factors that contribute to joint range of motion and stability, and explain the relationship that exists between range of motion and stability.
- Assess a joint's range of motion, evaluate the range, and describe desirable procedures for changing it when indicated.

Background

The mobility of joints is dependent upon several factors. The bony structure of the joint is the primary determinant of the type of motion allowed. The range of motion refers to the actual degree to which joint motion is able to occur.

Active range of motion is that arc of excursion or the degree of motion possible through voluntary muscle action. Passive range of motion is that range of motion possible without injury or discomfort through the action of an outside force.

For human joint range of motion averages please see Dr. Bob's ME 4670 / 5670 NotesBook, Appendix B.

If a goniometer is not available, you can make your own or simply use a protractor in all cases.

Procedures

1. Locate the following bony landmarks and mark lightly with a pen or chalk.

a. greater tubercle of humerus	e. greater trochanter (femur)
b. head of radius	f. lateral condyle of femur
c. styloid process of ulna	g. lateral malleolus
d. head of fifth metacarpal	h. proximal end, fifth metatarsal
2. Have the subject assume the base starting position for each joint measurement as follows:
 - a. Elbow flexion – From the anatomical position, shoulder abduction to 90° with the elbow fully extended and the hand in supination.
 - b. Wrist extension – same as above.
 - c. Hip flexion – Lie on a firm, flat surface in a supine position. With the knees bent, fully flex both hips.
 - d. Hip hyperextension – Lie prone on a firm, flat surface. Keeping both sides of the crest of the ilium in contact with the surface and the knee fully extended, hyperextend the right hip.
 - e. Knee flexion – Assume a supine lying position with the knee fully extended and the hip at approximately 45° - 50°. Use caution when performing passive knee hyperextension in this position.
 - f. Ankle – In a sitting position with the knee and ankle at 90°. The foot should be well clear of the floor. The goniometer axis must be below the malleolus.

3. Place the goniometer on the subject so that the fixed arm of the goniometer is along the mechanical axis of the proximal, or fixed, segment of the active joint.

The axis or 0° mark of the goniometer should be at the joint axis for the joint to be measured. Make sure that the protractor part of the goniometer is toward the direction of motion.

Place the moveable arm of the goniometer along the mechanical axis of the segment moved after the final range of motion position has been reached. Do not try to keep the goniometer on the moving segment during the motion.

All measurements should be done on the same side of the body.

4. Record your results for maximum active and passive range of motion in both flexion and extension (or hyperextension, or dorsiflexion/plantar flexion) of the Lab 3 Report. Answer all discussion questions.

5. Graph your results. A bar chart will work well, your team must arrange the plots for maximum graphical communication.

6. Include photos of your measurement setup. Also include annotated digital photos and/or sketches for all of your joint limits results.

Lab 3 Report – Range of Motion

Name(s) _____

Date _____

Ranges of Motion in Degrees

Joint	Flexion		Hyperextension	
	Active	Passive	Active	Passive
Elbow				
Hip				

Joint	Flexion		Extension	
	Active	Passive	Active	Passive
Wrist				
Knee				

Joint	Dorsiflexion		Plantar Flexion	
	Active	Passive	Active	Passive
Ankle				

1. Where did your active range of motion measurements fall outside the limits of those presented as average? (See Dr. Bob's ME 4670 / 5670 NotesBook, Appendix B, for active motions only.) Be specific as to joint name and amount of difference found.

Ranges of Motion Differences (+ or -)

Joint	Flexion	Hyperextension
Elbow		
Hip		

Joint	Flexion	Extension
Wrist		
Knee		

Joint	Dorsiflexion	Plantar Flexion
Ankle		

2. Speculate on specific reasons for you as an individual that might account for any for the differences you found in each joint.

3. Compare your active range of motion to your passive range of motion. In general, which of the two was greater?

How would you explain this difference?

4. What anatomical or structural factors either enhance or limit range of motion in each joint tested?

Lab 4. Center of Gravity (CG)

Objectives

- Define the term **center of gravity**, and explain the basis for its location in the human body.
- Locate the center of gravity of an individual using the **reaction board** and the **segmental method**.

Background

The center of gravity of a body is sometimes described as its balance point or that point about which a body would balance without a tendency to rotate. For this reason, the center of gravity is often identified as the point where all of the weight of the body or object is concentrated. More accurately, it is the point where the weight of the body may be said to act.

The ability to locate the center of gravity of a body is based on the knowledge of what it takes for a system to be balanced, or in equilibrium. There are two conditions that must be met:

- All the linear forces acting on the body must be balanced.
- All the rotary forces (torques) must be balanced.

Another way of expressing these necessary conditions for equilibrium is to say that the sum of all the forces acting on the body must equal zero. If there is a downward-directed linear force, there must be an equal upward force so that the vector sum of these forces equals zero. If there is a negative clockwise torque it must be canceled out by a positive counterclockwise torque of equal magnitude.

The location of the center of gravity of any object remains fixed as long as the body does not change shape. In rigid bodies of homogeneous mass, the center of gravity is at the geometric center. Where the density of a rigid body varies, the center of gravity is not at the geometric center but is shifted toward the more weighted section. If an object's shape or position changes, the location of the center of gravity will also change. This happens in the human body. It is a segmented structure, capable of numerous positions, and the location of its center of gravity changes accordingly. This is an important consideration in the execution of sports skills.

According to:

hypertextbook.com/facts/2006/centerofmass.shtml

“The average ratio of center of mass to height in females is approximately 0.543 and the average ratio of center of mass to height in males is approximately 0.560.” (measured from the ground).

That is, the center of gravity of average adult females is 54.3% of their height, measured up from the ground. The center of gravity of average adult males is 56.0% of their height, measured up from the ground. Thus, the center of gravity is usually located somewhat lower in women than in men.

Your team must use both the **reaction board** and the **segmental methods**, as stated above. However, if you cannot get ahold of all the required equipment, DO NOT buy anything – just do a virtual experiment, filling in appropriate numbers after using the numerical segmental method.

Reaction Board Method

It is a fairly simple matter to find an estimate of the center of gravity of a motionless body using the reaction board method. Making use of the principle of moments, this procedure relies on the statics principle that the sum of the moments acting on a body in equilibrium is zero. The center of gravity of the body is found according to the method below.

Equipment

Scales

Block (same height as the platform of the scales)

A board about 40 cm wide and $L = 200$ cm long with knife edge supports (see figure)

Procedure

1. Find the subject's total weight, W .
2. Put one knife-edge of board on scale platform and the other edge on box platform. Use a level to make sure the board is horizontal. Note the reading on the scales (without the subject). This is the partial weight of the board, B .
3. Have the subject lie supine on the board with the heels against the footrest at the end of the board away from the scales. The position the subject assumes should be as similar to the standing position as possible. Record the reading on the scales. This is the partial weight of the subject and board, S .
4. For static equilibrium to exist about the point P (the foot knife-edge support), the counterclockwise (+) torques must equal the clockwise (–) torques. Again, W is the total weight of the subject, B the partial weight of the board, S the partial weight of the subject and board, L the length of the board, and d the distance from P to the human body CG, then:

$$\sum M_x = 0$$

$$Wd = (S - B)L$$

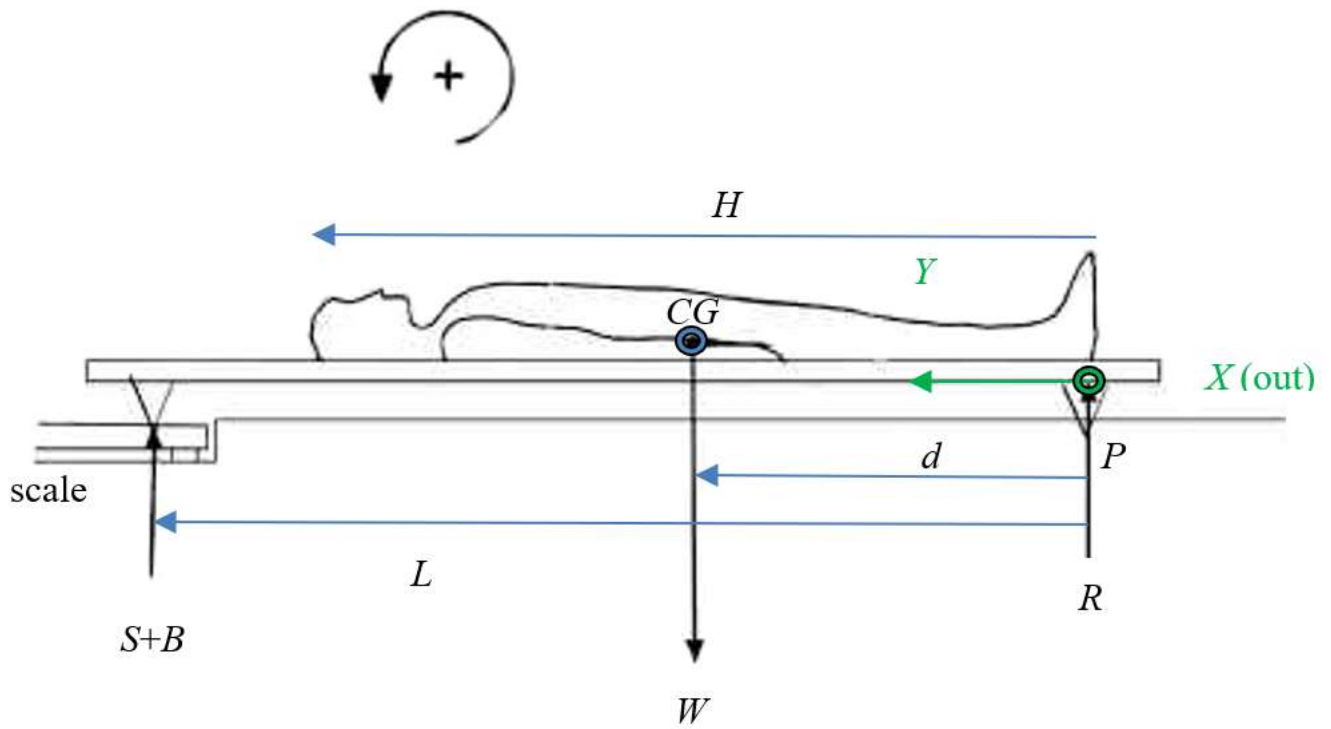
$$d = \frac{(S - B)L}{W}$$

The distance between the subject's feet and center of gravity is d . This is comparable to the distance between the ground and the center of gravity when the subject is standing, but must be viewed as an estimate because of shifts in body organs and tissues when lying down.

5. The percentage height of the center of gravity with respect to the subject's total height is found by dividing the value of d by the subject's total height H and multiplying by 100%.

$$\%_{CG} = \frac{d}{H} \times 100\%$$

Here is the associated figure. Draw your own figure in your report.



Reaction Board Method Figure

Segmental Method

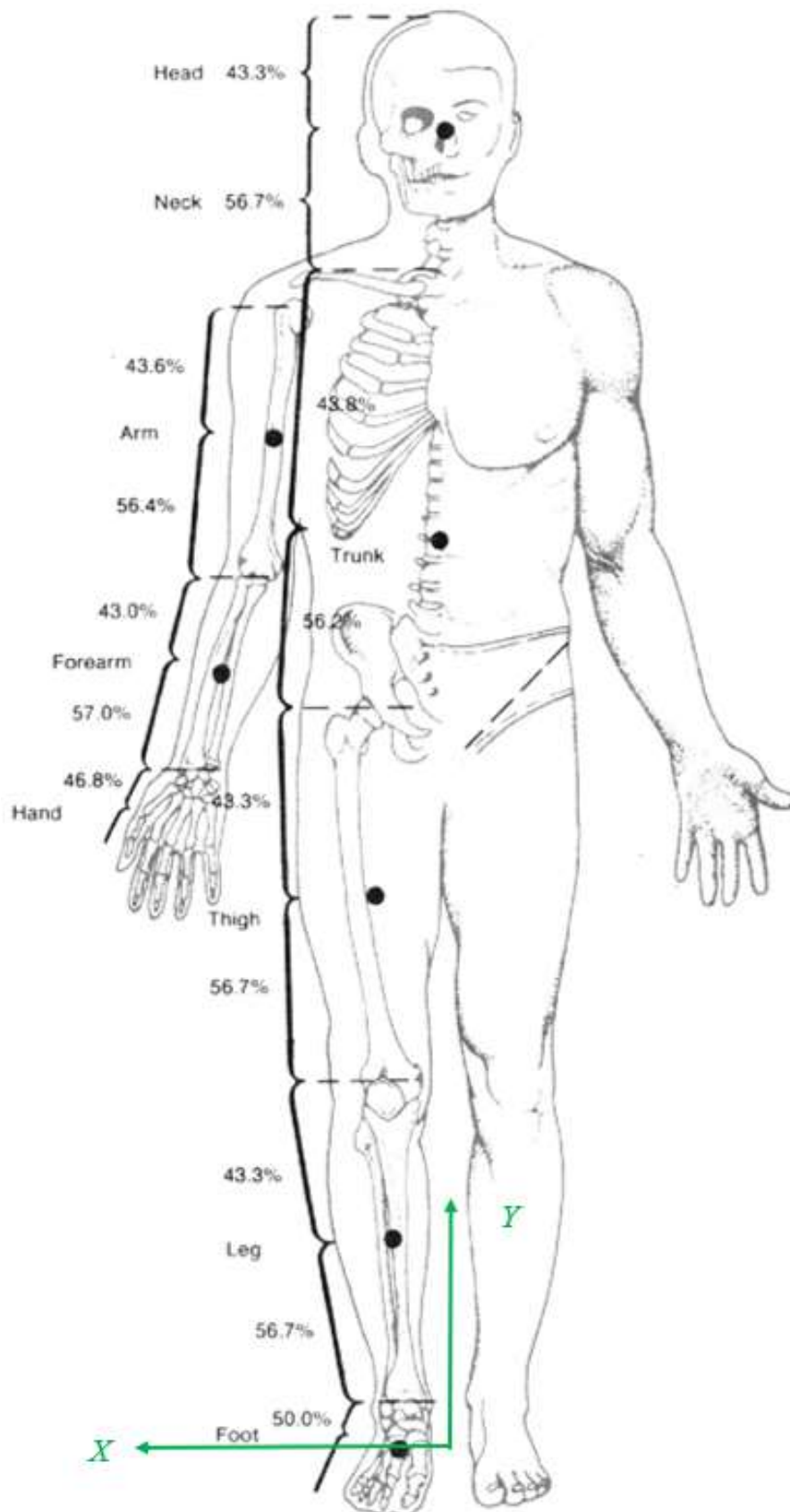
With information on the proportionate mass of body segments and the location of the center of gravity of each segment (see Appendix D), the center of gravity of the whole body in any plane may be determined by making use of the principle of torques. The sum of the torques of the individual segments about arbitrarily placed x and y axes will produce the location of the center of gravity of the whole body with respect to the x and y axes. This is because the total body weight acting at the center of mass is the resultant of the combined segment weights acting at their CGs and the resultant moment of the total body weight about the x, y axes is the sum of the individual segment torques about the same axes.

Equipment

Line drawing on graph paper

Procedure

1. Mark the locations of the extremities of the individual segments according to the link boundaries shown in the human CG figure of Appendix D of the ME 4670 / 5670 NotesBook.
2. The extremity limits are joined to form a stick figure consisting of 14 segments, some in series and some in parallel.
3. The CG location for each segment length is found using the data provided in the figure of Appendix D of the ME 4670 / 5670 NotesBook, where centers of gravity are located as a percentage of the distance between segment end points. The amount of the percentage distance from one segment end point is multiplied by the length of the segment. The resulting product is the distance from the selected end point to the center of gravity of the segment. The distance is measured from the end point, and the center of gravity is marked by the standard symbol. Caution – the segment CGs given in Appendix D are measured from the proximal end of each segment.
4. Draw x and y axes on the paper.
5. The x, y coordinates for each of the 14 segment CGs are determined and recorded on the diagram of the figure at the respective CGs.
6. Record the x, y coordinate values on the worksheet.
7. Multiply the x coordinate and the y coordinate each by the proportion of body weight listed in the second column. Record this result in the columns labeled x product and y product.
8. The algebraic sum of the x products represents the x coordinate of the total body's CG, and the algebraic sum of the y products is the y coordinate. These values are located and marked on the tracing.



Segmental Method Figure

Hamilton et al. (2008)

Lab 4 Report – Center of Gravity

Name(s) _____

Date _____

Reaction Board Method

Data to be used:

Subject's body weight (W)

Length of the board (L)

Weight of the pivoted board sensed by the scale (B)

Subject's height (H)

Weight of the subject while lying on the board (S)

1. Find height of the center of gravity measured from the feet.

$$d = \frac{(S - B)L}{W} =$$

2. Find the location of the center of gravity as a percentage of the total height.

$$\%_{CG} = \frac{d}{H} \times 100\% =$$

3. How does the location of your center of gravity compare with that presented as average for your gender (higher, lower, same)?¹

4. Provide an anatomical explanation for the location of your center of gravity as compared to the average.

¹ The average ratio of center of mass to height in females is approximately 0.543 and the average ratio of center of mass to height in males is approximately 0.560 (from the ground). <http://hypertextbook.com/facts/2006/centerofmass.shtml>

Segmental Method

Worksheet (use an Excel spreadsheet)

Body Segment	Proportion of Body Weight	x value	x product	y value	y product
Trunk	0.4684				
Head & Neck	0.0826				
R. Thigh	0.1050				
R. Lower Leg	0.0475				
R. Foot	0.0143				
L. Thigh	0.1050				
L. Lower Leg	0.0475				
L. Foot	0.0143				
R. Upper Arm	0.0325				
R. Forearm	0.0187				
R. Hand	0.0065				
L. Upper Arm	0.0325				
L. Forearm	0.0187				
L. Hand	0.0065				
x-y Resultants (product total)					

Lab 5. Work, Power, Friction, Elasticity

Objectives

- Explain the work-energy relationship as it applies to a body experiencing linear motion.
- Define and use properly the terms work, power, kinetic energy, and potential energy.

Background

Work is defined as the product of force and the distance through which that force moves an object, in the direction in which the force is applied ($W = F d$).

Power is the rate at which work is done ($P = W / t$).

Energy is defined as the ability to do work. Potential energy (PE) is energy based on position. Kinetic energy (KE) is energy based on motion. Energy within a system is conserved. That is, the total energy is the sum of PE and KE.

Friction is the tangential component of force which acts between two surfaces to resist sliding or rolling. The coefficient of friction is determined by the nature of the two surfaces.

Elasticity is the ability of an object to resist deformation and to resume its' original shape once it has been deformed. Elasticity is described in terms of an object coefficient of restitution.

Equipment

assortment of surfaces
assortment of balls
board marked at 10 cm and 20 cm
meter stick
steel ball bearing or golf ball
spring scale (see Friction section)
stopwatch
tape measure
weight

Lab 5 Report – Work, Power, Friction, Elasticity

Name(s) _____

Date _____

In all experiments, be careful to make sure that your units are consistent (you may not mix pounds with meters). Also in all experiments, make a drawing of the motion diagram including all important parameters.

Work & Power

Equipment: stopwatch, meter stick

You will need to record the following before you start:

Subject body weight (in Newtons) N

Vertical height of stairs m
(hint - measure a single step and multiply)

1. Time the subject as they walk up the stairs. Time:

Draw the motion diagram including all important parameters.

Calculate the work done and calculate the power produced.

$$W = F d$$

$$W =$$

$$P = W / t$$

$$P =$$

Briefly explain what these two quantities indicate in this experiment.

2. Repeat the experiment with the subject running up the stairs. Time:

Draw the motion diagram including all important parameters.

Calculate the work done: $W =$

How does this compare to the first trial?

Give a mechanical explanation for this comparison.

Calculate the power produced. $P =$

How does this compare to the first trial?

Give a mechanical explanation for this comparison.

Energy

Equipment: marked board, steel ball bearing or golf ball

3. Place the board on the floor with the 20 cm end propped up on some stable object (such as a book or a block). Start the bearing or ball at the 10 cm mark on the board. Release the bearing or ball and let it roll. Record the time it takes to travel the first meter after it leaves the board. Record the total distance the bearing travels. Record the height of the board at the 10 cm mark.

Draw the motion diagram including all important parameters.

Mass of shot (kg)

Height of 10 cm mark (m)

Time for 1st meter (sec)

Calculate the potential energy possessed by the bearing before release.

$$PE = mgh \quad PE =$$

Calculate the kinetic energy possessed by the bearing in motion.

$$KE = \frac{1}{2} m v^2 \quad KE =$$

Are the potential energy and the kinetic energy approximately the same?

Give a mechanical explanation for this result.

Calculate the frictional force that was applied to the bearing to bring it back to rest.

$$\text{Total distance (d, m)} \quad F = KE / d \quad F =$$

4. Repeat the experiment, but start the bearing from the 20 cm mark on the board. Record the time taken to cover the first meter, the total distance covered, and the height of the 20 cm mark.

Height of 20 cm mark (m)

Time for 1st meter (sec)

Calculate the potential energy possessed before release.

$$PE = mgh \qquad PE =$$

Calculate the kinetic energy possessed in motion.

$$KE = \frac{1}{2} m v^2 \qquad KE =$$

Are the potential energy and the kinetic energy approximately the same?

Give a mechanical explanation for this result.

Calculate the frictional force that was applied to the bearing to bring it back to rest.

$$\text{Total distance (d, m)} \qquad F = KE / d \qquad F =$$

5. Do the following comparisons between the two trials.

Which of the two trials possessed the greatest PE?

Why was this so?

Which of the two trials produced the greatest KE?

Give a mechanical explanation for this result.

In which trial was the greatest force generated?

Give a mechanical explanation for this result.

Repeat Experiment 2 with other balls. Record your results on a separate sheet of paper.

Friction

If you do not have access to a spring scale, do not buy one. Instead, turn the experiment around (research on the Internet to find common coefficients of friction μ for a shoe on various surfaces) and perform the friction experiment (Steps 6, 7, and 8) using calculations instead of measurements.

Equipment: weighted shoe, spring scale, a variety of surfaces (floor, a board, carpet, AstroTurf, artificial track, etc.)

6. Place the weight in the shoe. Attach the spring scale to the shoe and weigh it (W). Place the shoe on a wooden board. Pull horizontally on the spring scale just until the shoe starts to move. Make sure you do not exert any upward force on the shoe, as this will reduce friction. Read the pulling force (P) from the scale and record it below.

Draw the motion diagram including all important parameters.

W =

P =

Calculate the coefficient of friction (μ).

$\mu = P/W$ $\mu =$

7. Repeat this experiment on as many different surfaces as you can find.

Surface	P	μ

Which of these surfaces produced the greatest coefficient of friction?

Give a mechanical explanation for this result.

8. Place the weighted shoe on the board. Now tilt the board until the shoe just barely begins to slide. Measure the angle between the board and the floor. The tangent of this angle will be the coefficient of friction (derive this result).

$$\mu = \tan\theta$$

$$\mu =$$

Does this agree with the μ you found in trial #1 of this experiment?

Give a mechanical explanation for this result.

Elasticity

Equipment: an assortment of balls

9. Fix a tape measure to a vertical surface. Drop each ball in turn from a height of 2 meters onto the floor. Measure the height. Coefficient of elasticity:

$$e = \sqrt{\frac{\text{height of rebound}}{\text{height of drop}}}$$

Ball	Rebound height	<i>e</i>

Draw the motion diagram including all important parameters.

Which ball has the greatest observed elasticity?

Give a mechanical explanation for this result.

10. Repeat the experiment using as many different landing surfaces as you have time for. (Record your results on an additional piece of paper.)

What were the effects of the different surfaces on the elastic response of the balls?