ME 467 / BME 567

Engineering Biomechanics of Human Motion

Laboratory Exercises

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These laboratory exercises are 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.

Table of Contents

Laboratory Report Format

This section presents a recommended report format for the ME 467 / BME 567 laboratories all term. 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 graphics/digital photos and good discussion on all points.

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

1. Objectives

2. Background

3. Results

4. Discussion

5. Conclusion

References

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 term – indeed, in all of your engineering work in the future.

The amount of significant figures in any number is 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 ½ 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, $2\underline{0}0$ has two sig figs, and $20\underline{0}$ 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 (Vx) and vertical velocity (Vy) 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 Vx and Vy the sine and cosine functions are used. The horizontal velocity of the jump Vx 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 hundredth decimal place.

Lab 1 Report – Vectors

Name(s)____ Date_______________

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

statics

dynamics

kinematics

kinetics

scalar

vector

2. Express the following units in metric terms:

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 between each set of points (scale: 1 unit = 10 cm). Draw a vector diagram to approximate 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.

a. 45 m/sec at 25°

b. 85 N at 135°

c. 118 N at 310°

d. 25 m/sec2 at 210°

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 muscular force of a muscle is 650 N and the muscle is pulling on the 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? In feet/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? 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), 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.

b. Determine the resultant displacement graphically.

c. Determine the resultant displacement trigonometrically.

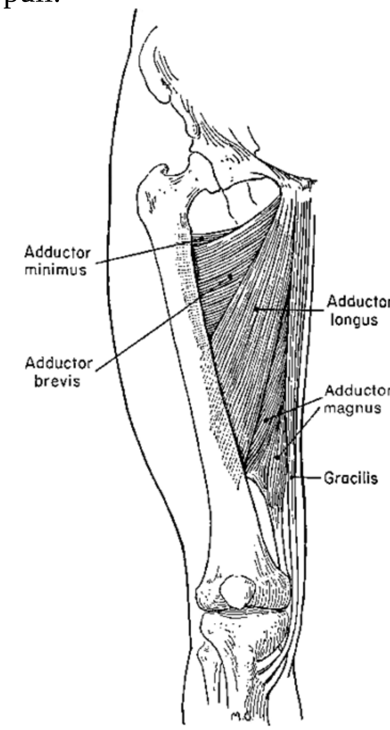
d. Explain any differences you have between your graphic and trigonometric results.

e. Express the orienteer's position at the end of the course in terms of rectangular coordinates.

Polar coordinates.

10. A football lineman charges an opponent with a force of 175 pounds in the direction of 310 degrees. The opponent charges back with a force of 185 pounds in the direction of 90 degrees. 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 mechanical axis of the femur and another to represent the muscle's 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**).

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

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)?

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 with any outside surface by either the hands or the 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. Mark its landing point. Next, toss the ball up to yourself and hit it. Mark the landing. Finally, hit a ball that is pitched to you. Mark the landing. Use a consistent swing speed throughout the experiment.

Draw the motion diagram including all important parameters.

Which ball went farther?

Give a mechanical reason for this result:

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 diagram 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. again hold the weights. 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.

Which jump was the longest?

Give at least 2 mechanical reasons for this result:

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 on-line 467/ NotesBook Supplement, Appendix B.

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 hyperextension - 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 lium in contact with the surface and the knee fully extended, hyperextend the right hip.

e. Knee - 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 hyperextension of the Lab Report. Answer all discussion questions.

5. Graph your results.

6. 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				
Wrist				
Hip				
Knee				
Ankle				

1. Where did your active range of motion measurements fall outside the limits of those presented as average? (See Dr. Bob's on-line 467/ NotesBook Supplement, Appendix B.) Be specific as to joint name and amount of difference found.

Ranges of Motion Differences (+ or -)

Joint	Flexion	Hyperextension
Elbow		
Wrist		
Hip		
Knee		
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. Introduction to Kinesiological Analysis

Objectives

- Describe the major components of a kinesiological analysis.
- Prepare a description of a selected motor skill, breaking the skill down into component phases and identifying starting and ending points.
- Determine the simultaneous - sequential nature of a variety of movement skills.
- Classify motor skills using the classification system presented.
- State the mechanical purpose of a variety of movement skills.
- Utilize methods of observation and palpation to identify the joints and basic muscle groups active in a movement skill.

Background

A kinesiological analysis is the application of this information to assessing the effectiveness of a given motor performance. It consists of

- describing a skill in a logical and systematic fashion by breaking it down into its constituent elements
- evaluating the performance of the skill by determining whether and how the related anatomical and mechanical principles have been violated
- prescribing corrections based on an appropriate identification of the cause or causes.

The first step in the description phase of the analysis is to identify the primary purpose of the movement. Without a clear understanding of why the movement is being performed, it is virtually impossible to evaluate its effectiveness. In this statement of purpose, applicable references to speed, accuracy, form, and distance should be included.

Motor skills take many forms and are used for many purposes. A classification scheme is important because it permits the variety of potential movement skills to be organized into a manageable grouping. This manner of organization facilitates the recognition of commonalities across movements. It also fosters increased understanding by enabling one to focus upon either differences or similarities in movement patterns, as the situation demands. Classification of movement patterns and skills provides further clues as to the nature of both the anatomical and mechanical requirements of a particular group of skills.

A **system for the classification of movements** is presented on the following page. To simplify the complexities of the wide range of possibilities presented, it is important to understand that when motions are combined, bodily movements may be classified as occurring on a continuum ranging from the simultaneous to the sequential use of the body segments. The simultaneous use of the body segments, where the various segments move as one, is exemplified by motions such as pushing, pulling, or lifting objects. In a simultaneous movement pattern, all of the movement is directed along a straight line. Simultaneous use of body segments is the only way it is anatomically possible to move the hand or foot in a straight line. This straight-line application of force by the hand or foot is the most advantageous method to use when overcoming heavy or large objects or external forces such as those encountered in pushing file cabinets and lifting weights.

When it is important to have maximum speed at impact or release, a sequential use of the body segments is appropriate. The use of the segments in an orderly sequence so that subsequent segments are accelerated at the appropriate time to create the highest possible speed is critical in activities exemplified by throwing, striking movements such as batting or the golf drive, and kicking. Sequential movements produce forces applied so that the final segment moves along a curved path. The farther this curved path is from the center of the motion, the greater will be the speed of the throwing, striking, or kicking segment.

Motions may occur anywhere along this simultaneous-sequential continuum or may combine the two basic forms.

The anatomical analysis of a movement should include an examination of the skeletal joint action, a description of segment motion, and an account of the muscle participation.

System for Classification of Motor Skills (Hamilton et al., 2008)

I. Maintaining erect posture

II. Movement for exercise and fitness

III. Giving motion
- A. To external objects
  1. Pushing and pulling
     - a. Lifting and carrying
     - b. Punching
  2. Throwing, striking, and kicking

- B. To one's own body
  1. Supported by the ground or other resistant surface
     - a. Locomotion on foot
     - b. Locomotion on wheels, blades, and runners
     - c. Rotary locomotion
  2. Suspended and free of support
     - a. Swinging activities on trapeze, flying rings, or similar equipment
     - b. Hand traveling on traveling rings or horizontal ladder
     - c. Unsupported – i.e. projected into or falling through the air
     - d. Weightlessness
  3. Supported by water
     - a. Swimming
     - b. Aquatic stunts
     - c. Boating

IV. Receiving impact
- A. From one's own body in landing from a jump or fall

- B. To one's own body

Underlying Mechanics Objectives (Hamilton et al., 2008)

To explain the mechanical factors that contribute most to performance, it is first necessary to define clearly the purpose or objective of the motion involved. The focus of the statement of mechanical objective will be on the desired outcome of the motion, which is necessary to measure effectiveness. Several systems have been proposed for the classification of mechanical objectives of human movement. A synthesis of many of those systems is presented here as a simplified set of objectives.

The underlying objective of a motion may be:

1. Balance
   a. Regain stability
   b. Attain mobility

2. Locomotion
   a. Travel from point to point
   b. Travel a prescribed distance
   c. Travel a prescribed pattern

3. Projection
   a. For maximum height
   b. For maximum range
   c. For maximum accuracy
   d. For optimum speed and accuracy

4. Manipulation
   a. Of objects
   b. To reproduce a pattern
   c. Of a resistance

5. Maximum effort
   a. Maximum speed
   b. Maximum power
   c. Maximum force

Each of these underlying mechanical objectives requires consideration of different but overlapping sets of mechanical factors. The standing long jump, for instance, has the underlying mechanical objective of projection of the body for maximum range (distance). The question now becomes one of determining what must be done in mechanical terms to produce the maximum distance. Because the distance traveled is in the air, the body becomes a projectile, and those factors that cause the projectile to travel the farthest are those that must be considered.

Lab 4 Report – Introduction to Kinesiological Analysis

Name(s)____ Date______________

1. Select three motor skills, using movements that appear to be quite different in nature.

Skills selected: Sketches (or attach digital photos):

a.

b.

c.

Classify each skill according to the **System for Classification of Motor Skills** (given previously).

a.

b.

c.

Identify the **Underlying Mechanics Objective(s)** for each skill, using the outline given previously.

a.

b.

c.

2. Using a simple skill of the student's choosing, prepare a qualitative description of a motor skill. Follow the outline provided:

Purpose of the motion

Simultaneous-sequential nature of the motion (give a rationale for your answer).

Provide a brief, simple description of the motion. Use language that would be appropriate for explaining this motion to a young student, not a kinesiologist.

Describe the phases into which you will break this motion. Each phase description should include a clear and concise description of the starting and ending actions that define the phase. Include ***sketches*** for each phase.

3. Using the skill from #2, utilize methods of observation and palpation to identify the joints and basic muscle groups involved in the motion.

Phase___________________________

Joint	Muscle Groups

a.

b.

c.

d.

e.

f.

g.

h.

Phase___________________________

Joint	Muscle Groups

a.

b.

c.

d.

e.

f.

g.

h.

3. (continued, if necessary)

Phase____________________________

Joint	Muscle Groups
a.	
b.	
c.	
d.	
e.	
f.	
g.	
h.	

Phase____________________________

Joint	Muscle Groups
a.	
b.	
c.	
d.	
e.	
f.	
g.	
h.	

Lab 5. Anatomical Analysis

Objective

Perform a complete anatomical analysis of a motor skill.

Background

In order to produce a meaningful analysis of movement it is necessary to use an organized system for analysis. Human body motions can be classified on a continuum ranging from the simultaneous to sequential motions of body segments. To clarify analysis it is beneficial to break a motion down into phases. Some commonly used motion phases are preparation, execution, and recovery (alternatively: preparation, execution, flight, and landing works well for jumping).

In this analysis model, the student will identify the joint, joint motion, the segment being moved by that motion, the appropriate plane and axis in which the motion occurs, the nature of the force which produces the motion, the muscle contraction type being utilized, and the muscles which act as prime movers. Generally speaking, the segment being moved will be determined by the condition of the distal end of the extremity involved. If the distal end of that extremity is fixed (immobilized), the segment moved through motion at a joint will be the segment proximal in relation to that joint. If the distal end of the extremity is free, the segment moved will be that which is the distal segment in relation to the joint.

It is useful to identify the force that produces a motion before attempting to identify the prime movers or contraction type. If the motion is horizontal or in an upward direction (and no outside force is present), muscle force is producing the motion. In this case, the muscle contraction type would be concentric. The prime movers are listed in Dr. Bob’s 467/567 NotesBook™ and Supplement for the observed joint motion. If the motion is in a downward direction, slower than what would be produced by a simple fall, gravity is the force. In this case, the contraction type would be eccentric, as the muscles are controlling the speed of the movement.

Procedures

In this lab you will be doing an analysis of a jumping motion. You may choose either a standing long jump or a standing vertical jump for analysis; analyze the entire motion for your jump of choice.

Have one member of your group act as a subject. The subject will perform the required motion as needed. Working from the ankle (point of force production) to the shoulder, produce a complete anatomical analysis for the jump your group chose. Record your analysis on the form provided. The joints that should be included in your analysis are the ankle, knee, hip, shoulder, elbow, and trunk (vertebral column). There is motion that takes place distal to the ankle, which can be ignored in this analysis. Also, for simplicity’s sake, deal with the trunk as a single joint. The trunk, therefore, becomes both the joint and the segment moved in that portion of the analysis.

Record your analysis on the report form provided. Be sure to specify the appropriate phase for each analysis page. It is a good idea to include graphics: annotated digital photos or sketches.

Lab 5 Report – Anatomical Analysis

Name(s)____ Date______________

1. What jump did your team choose? Who was the subject?

2. Describe the motion involved in each phase of the jump. Be sure to include a description of when each phase begins and ends.

Include a detailed description in words above. Then summarize your results in tables on extra pages – the table headings come from the second paragraph of the background on the previous page. Include ***sketches*** for each phase of your team's jump.

Lab 6. Center of Gravity

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 either the reaction board or 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. It has been estimated that the center of gravity of most individuals falls between 55% and 59% of the total body height. It has further been established that the center of gravity is usually located somewhat lower in women than in men.

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 fact that the sum of the moments acting on a body in equilibrium is zero. Using this information the location of the gravitational line is found for each plane. The center of gravity of the body becomes the intersection of the values for each of these three planes. Directions for locating the center of gravity in three planes follow.

Equipment

Scales (the Toledo or the spring balance type)
Block (same height as the platform of the scales)
A board about 40 cm wide and 200 cm long with knife edge supports

Procedures

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 spirit level to make sure board is horizontal. Note the reading on the scales. 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 scales, S.

4. For equilibrium to exist about the point P, the counterclockwise torques must equal the clockwise torques. If 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 perpendicular distance from P to W, then

$$d \times W = (S-B)L$$

(clockwise torques = counterclockwise torques)

Rearranged,

$$d = [(S-B)L] / W$$

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 in the transverse plane (supine lying position) by the subject's total height and multiplying by 100.

$$\text{percent} = (\text{d in transverse plane} / \text{subject's height}) \times 100\%$$

Draw figure:

Segmental Method

With information on the proportionate mass of body segments and the location of the center of gravity of each segment, 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 mass centers 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

Procedures

1. Mark the locations of the extremities of the individual segments according to the link boundaries shown in Figure 14.18 (end of the second toe, ankle, knee, hip, knuckle III of the hand, wrist, shoulders, seventh cervical vertebra, midpoint of the transverse line joining the hips, and top of the head).

2. The extremity limits are joined to form a stick figure consisting of 14 segments.

3. The mass center location for each segment length is found using the data provided in Figure 14.18, 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 picture-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 a short slash mark intersecting the segment line.

4. Draw x and y axes on the paper.

5. The x, y coordinates for each of the 14 segment mass centers are determined and recorded on the diagram of the figure at the respective mass centers.

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 mass center, and the algebraic sum of the y products is the y coordinate. These values are located and marked on the tracing.

Lab 6 Report – Center of Gravity

Name(s)____ Date______________

Reaction Board Method

Data to be used:

Subjects body weight (W)

Length of the board (I)

Weight of the board (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:

$$d = [(S - B)L] / W$$

d =

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

$$\text{percent} = (d/H) \times 100\%$$

percent of height =

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

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

Segmental Method

Worksheet (use an Excel spreadsheet):

Body Segment	Proportion of Body Weight	x value	x product	y value	y product
Trunk	0.486				
Head & Neck	0.079				
R. Thigh	0.097				
R. Lower Leg	0.045				
R. Foot	0.014				
L. Thigh	0.097				
L. Lower Leg	0.045				
L. Foot	0.014				
R. Upper Arm	0.027				
R. Forearm	0.014				
R. Hand	0.006				
L. Upper Arm	0.027				
L. Forearm	0.014				
L. Hand	0.006				
x-y Resultants (product total)					

Lab 7. Analysis of Push-Pull Motions

Objectives

- Name and discuss anatomical and mechanical factors and principles that apply to representative push or pull activities.
- Analyze the performance of someone performing a push-pull skill under each of these force application conditions: momentary contact, projection, or continuous application.

Background

In pushing and pulling patterns of motion, the basic joint actions are flexion and extension in one or more of the extremities. The joint actions in the upper extremities are characterized by flexion and extension in the elbow while the opposite movement is occurring in the shoulder. In the lower extremities, extension occurs simultaneously in the hip, knee, and ankle. This simultaneous and opposite joint action is a primary characteristic of push-pull patterns. All joint motions occur at the same time or very near the same time.

The simultaneous nature of the joint motions in push and pull patterns produces a rectilinear path of motion at the distal end point of the segments involved, as opposed to a curvilinear path. Such a rectilinear path means that all forces produced by segmental motion are applied directly to the object and that this force is applied in the direction of motion. Keeping this in mind makes it apparent that the primarily simultaneous push-pull patterns are of greatest value when it is important to apply a large force (overcome a large resistance) or to apply a force with maximum accuracy. All the forces involved are applied directly in line with the object being moved. There are no large-magnitude tangential forces.

A push, pull, or lift may be applied either directly or indirectly to an object. In the latter instance, the push or pull pattern is used for the purpose of developing potential energy in an elastic device such as a bow or slingshot. When the elastic structure is released, it imparts force to the movable object, causing the arrow or shot to be projected into the air.

Procedures

Working with your partner, select a simple push-pull skill.

From the **movement principles** listed on the next page, derive a qualitative checklist for this skill. The checklist should include all of the critical elements necessary to insure that this skill is performed with optimum safety, effectiveness, and efficiency.

For each critical element included as part of the checklist, provide a rationale for inclusion.

Have one student act as a subject and perform the selected skill. Apply the checklist that has been developed to the performance. Based on the qualitative checklist evaluation, make suggestions for improvement of the skill performance, based on sound mechanical principles.

Push-Pull Movement Principles (Hamilton et al., 2008)

Principles relating to the magnitude of force:

1. The object will move only if the force is of sufficient magnitude to overcome the object's inertia.

2. Force exerted by the body will be transferred to an external object in proportion to the effectiveness of the counterforce of feet (or other body parts) against the ground (or other supporting surface).

3. Optimum summation of internal force is needed if maximum force is to applied to move an object.

4. For maximum accuracy, the smallest possible number of segments should be used through the smallest possible motion range.

5. For a change in momentum to occur, force must be applied over time (impulse); maximum forces require maximum time ranges of application.

Principles relating to the direction of force:

1. The direction in which the object moves is determined by the direction of the force applied to it (Newton's Second Law).

2. If an object is free to move only along a predetermined path (e.g. a sliding door), any component of force not in the direction of this path is wasted and may increase friction.

3. When optimum force production is the purpose of the push or pull pattern, those segments involved should be aligned with the direction of intended force production.

Principles relating to the point at which the force is applied:

1. Force applied in line with an object's center of gravity will result in linear motion of the object, provided it is freely movable.

2. If the force applied to a freely movable object is not in line with the object's center of gravity, rotary motion will result.

3. If the free motion of an object is interfered with by friction or by the presence of an obstacle, rotary motion may result, even though the force is applied in line with the object's center of gravity.

Lab 7 Report – Analysis of Push-Pull Motions

Name(s)____ Date_______________

Push-pull skill selected (clearly state in your memo also):

Checklist:

1.

Rationale:

2.

Rationale:

3.

Rationale:

4.

Rationale:

Attach additional numbers as necessary.

Sketches for your push-pull skill (one for each step in the checklist):

Selected skill:____ Performer ______________________

Checklist Items

	Yes	No
1.	______	______
2.	______	______
3.	______	______
4.	______	______

Attach additional numbers as necessary.

Are there any noticeable deviations from the performance described by the checklist? If so, describe each one:

What is the probable cause of each of these deviations?

What specific suggestions would you make for the improvement of performance?

Rationale:

Lab 8. 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
stopwatch
tape measure
weight

Lab 8 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: 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 PE =

Calculate the kinetic energy possessed by the bearing in motion:

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

Total distance (d, m) F = KE / d 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 PE =

Calculate the kinetic energy possessed in motion:

KE = ½ m v^2 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:

Total distance (d, m) F = KE / d 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

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 weight 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**	***e***

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?

Lab 9. Torque

Objectives

- Solve simple lever and torque problems involving the human body and the implements it uses.
- Evaluate the true muscular effort force required to support a given external resistance.
- Enhance understanding of the nature of torque and the effects of torque on the body.

Background

The turning effect of an eccentric force is called torque or moment of force. The torque about any point equals the product of the force magnitude and the perpendicular distance from the line of force to the axis of rotation. The perpendicular distance between the force vector and the axis is called the moment arm or torque arm. In this text, the turning effect will be referred to as torque and the perpendicular distance as moment arm.

Since torque is the product of force and the length of the moment arm, it may be modified by changing either the force or the moment arm. Torque may be increased by increasing the magnitude of the force or by increasing the length of the moment arm. Decreasing either of these factors will produce a decrease in torque. In supporting a weight at the end of a fully extended arm for instance, if the magnitude of the weight were decreased, the torque would also decrease. Conversely, increasing the weight would increase the torque. If, however, the weight is increased but is moved closer to the axis (the elbow), the torque produced by the heavier weight would be reduced through reducing the length of the moment arm.

It is important to emphasize that the moment arm is the perpendicular distance from the direction of force to the axis of rotation. In the example just given, the moment arm length was the same as the length of the forearm because the horizontal forearm was perpendicular to the vertical direction of the force, and therefore the forearm length was equal to the perpendicular distance from the force direction to the axis. If the arm were in some position other than the horizontal, its length would no longer be equal to the moment arm distance between the force direction and axis. Only the rotary component (y component) of a force acts to produce torque. The x component will act either to stabilize or dislocate the joint.

Torque is a function of an applied force times the distance from the axis at which that force is applied ($T = F \times d$).

Forces can be either effort or resistance forces. For a system or a lever to be in equilibrium these two types of forces must create equal and opposite torques ($E \times EA = R \times RA$).

Torque acts at the joint. Force acts on a lever.

Equipment

Meter stick
Load (a book bag with books inside works well)
Stopwatch
Goniometer

Procedures

1. On your subject locate the lateral femoral condyle and the lateral malleolus of the right leg. Measure the distance between the two landmarks and record this on your lab report as segment length.

2. Using the converted weight of the subject (see lab report) determine the weight of the lower leg. Use the data provided to find the location of the center of gravity of the lower leg, as measured from the knee.

3. Record the leg weight and the distance to the center of gravity on the free body diagrams (FBD) provided. This will represent R1 and RA1.

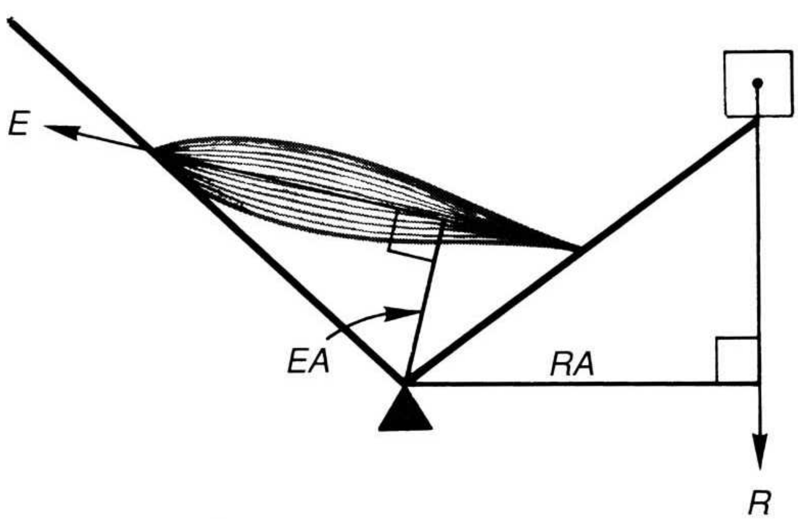
4. Calculate the location of the attachment of the quadriceps muscle group to the tibia using the percentage given on the lab report. Record this on the free body diagram representing EA. Notice the muscle angle of pull given on each FBD.

5. Have the subject sit on a table. Fix equal loads to each ankle. Have the subject then extend the left leg as fully as possible (with the thigh fully supported). The right knee is extended to an angle of 150°, determined by goniometer (that is, drop the lower leg down 30° from horizontal knee extension).

6. Hold these positions as long as possible. Record the holding time for each leg.

7. Record the magnitudes of the external loads on the lab report form and on the two FBDs. These will represent R2. Record the segment length on the two FBDs, representing RA2.

8. Using standard torque calculation techniques, calculate the actual muscle force required by the quadriceps muscle group of each in order to support the external load.



Biceps-Like Moment Diagram

E – effort force *EA* – effort moment arm
R – resistance force *RA* – resistance moment arm

Lab 9 Report – Torque

Name(s)____ Date_______________

Record the following information and do the required calculations to produce the relevant data.

Body weight lbs. X 4.45 = N

Segment weight (R1) = body weight N X 0.045 = N

Segment length (RA2) meters

Center of gravity location (RA1):

Segment length meters X 0.433 = meters

Muscle attachment (EA):

Segment length meters X 0.12 = meters

External load (R2) lbs. X 4.45 = N

Fill in the free body diagrams (FBDs) for both legs with this data.

Draw figure:

Data to be used:

R_1 (segment weight) N RA_1 (center of gravity) m

R_2 (external load) N RA_2 (segment length) m

EA (effort arm, distance to muscle attachment) m

RA is resistance arm for the loads

Calculate torque produced by the resistance:

$(R_1 \times RA_1) + (R_2 \times RA_2) = T_R$

$T_R =$ Nm

Calculate the rotary component of the muscle force required to produce an equal and opposite torque:

$T_R = E_y \times EA$ therefore $E_y = T_R/EA$

E_y N

Calculate the total muscle force:

$E = E_y/\sin 15°$

E N Time held: sec

Draw figure:

Calculate the rotary components of the resistance forces:

R_{1y} N R_{2y} N

Calculate the torque produced by the resistance:

$(R_{1y} \times RA_1) + (R_{2y} \times RA_2) = T_R$

$T_R =$ Nm

Which of the two resistance torques is greater (straight leg or bent leg)?

What is the reason for this?

Calculate the rotary component of the muscle force required:

$E_y = T_R/EA$

E_y N

Calculate the total muscle force required to produce an equal and opposite torque:

$E = E_y/\sin 20°$

E = N Time held sec

In which leg was the greatest muscle force required?

Using the concept of torque and the principle of levers in equilibrium, explain why this is so:

Which leg had the longest holding time?

Explain this result. Base your answer on the answer to the previous question.