Lab # 3 - Angular Kinematics

Purpose:

The objective of this lab is to understand the relationship between segment angles and joint angles. Upon completion of this lab you will:

- Understand and know how to calculate absolute and relative angles.
- Be able to generate angle-angle diagrams from experimental data.

Introduction:

Angular kinematics refers to the kinematic analysis of angular motion. Angular motion occurs when all parts of an object move through the same angle but do not undergo the same linear displacement. The object rotates around an axis of rotation that is a line perpendicular to the plane in which the rotation occurs. Examples of angular motion are the motion of a bicycle crank as you pedal across campus and the motion of your thigh around your hip joint as you walk to class.

An understanding of angular motion is critical to comprehend how we move. Nearly all human movement involves the rotation of body segments. The segments rotate about the joint centers that form the axis of rotation for these segments. When an individual moves, the segments generally undergo both rotation and translation. Angular motion of anatomical joints also reflects changes in length of muscles crossing the joint.

The relationships discussed for linear kinematics are comparable to those in angular kinematics:

Angular kinematic variables:

Angular position (θ) = the angle of a segment or joint, measured in radians or degrees.

Angular displacement ($\Delta\theta$) = the difference between the initial and final angular positions of the rotating object ($\Delta\theta = \theta_{final} - \theta_{initial}$)

Angular velocity (ϖ) = change in angular position over a period of time ($d\theta/dt$)

Angular acceleration (α) = change in angular velocity over a period of time ($d\omega/dt$)

Measuring Angles:
An angle is composed of two lines that intersect at a point called the **vertex**. In a biomechanical analysis, the intersecting lines are generally body segments and the vertex is their common joint. If you consider the longitudinal axis of the shank segment as one side of an angle and the longitudinal axis of the thigh segment as the other side, the vertex would be the joint center of the knee.

Angles can be determined from the coordinate points you generated in the previous lab. Coordinates of the joint centers determine the sides and the vertex of the angle. For example, an angle at the knee can be constructed using the thigh and shank segments. The coordinates of the ankle and knee joint centers define the shank segment, while the coordinate of the hip and knee joint centers define the thigh segment. The vertex of the angle is the knee joint center.

Angular measurements are presented in **radians** or **degrees**. (2π radians = 360°).

Absolute angle: the orientation of a segment in space; the angle of inclination of a body segment. Segment angles are referred to as absolute angles measured from the right horizontal placed at the distal end of the segment. The following are segment angles:

θ_{foot} θ_{thigh}
θ_{shank} θ_{trunk}

Relative angle: the joint angle; the included angle between the longitudinal axes of two adjacent segments. The following are joint angles:

θ_{ankle}
θ_{knee}
θ_{hip}

Relative angles can be determined from the absolute angles.

$$\theta_{hip} = \theta_{trunk} + (180 - \theta_{thigh})$$
$$\theta_{knee} = \theta_{shank} + (180 - \theta_{thigh})$$
$$\theta_{ankle} = \theta_{shank} + (180 - \theta_{foot})$$

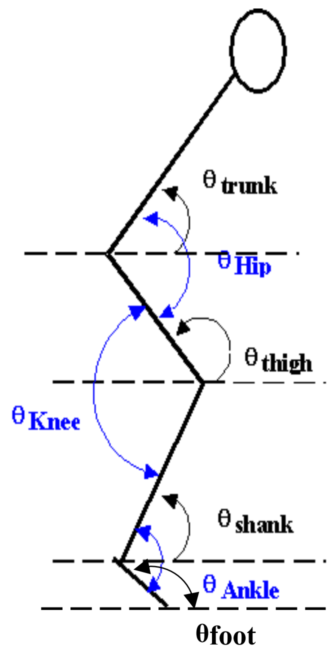


Figure 1. Relative and absolute angles.

Calculating Angles

Absolute and relative angles may be calculated using Microsoft Excel. Before being able to calculate these angles, however, the x and y coordinates of particular body landmarks must be known. For example, the heel and toe coordinates must be known in order to calculate the angle of the foot segment. Similarly, the knee and ankle coordinates must be known in order to calculate the shank segment angle.

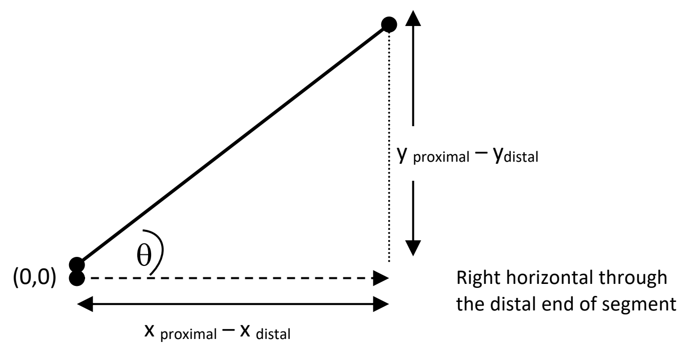
Absolute Angles:

To determine absolute joint angles, you need to define a reference system first. Here, we will choose the distal joint as our origin (0,0), and calculate the absolute segment (foot, shank, thigh, and trunk) angles from the right horizontal. Mathematically, the absolute angle can be calculated using the following trigonometric relationship:

$$\tan(\theta) = (y_{proximal} - y_{distal}) / (x_{proximal} - x_{distal})$$

taking the inverse tangent of both sides gives you:

$$\theta = \tan^{-1}((y_{proximal} - y_{distal}) / (x_{proximal} - x_{distal}))$$



In Excel, the inverse tangent formula calls for the x value *then* the y value, separate by a comma. So, in Excel, the absolute angle is calculated using the following formula:

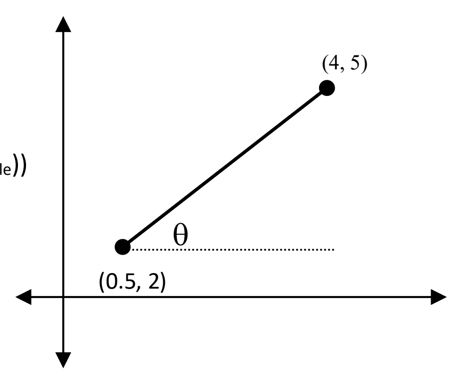
= ATAN2($x_{proximal} - x_{distal}$, $y_{proximal} - y_{distal}$)

Example: If the knee and ankle coordinates are (4,5)m and (0.5 2)m, respectively, then we can calculate the shank angle as follows:

Proximal joint: knee (4,5)
Distal joint: ankle (0.5,2)

Mathematically: $\theta_{shank} = \tan^{-1}((y_{knee} - y_{ankle}) / (x_{knee} - x_{ankle}))$
$= \tan^{-1}((5 - 2)/(4 - 0.5))$
$= 0.708$ rad or $40.6°$

In Excel: θ_{shank} = ATAN2 ($x_{knee} - x_{ankle}$, $y_{knee} - y_{ankle}$)
= ATAN2(4 – 0.5, 5 – 2)



The resulting segment angles are given in radians between $-\pi$ and π, excluding $-\pi$. Angles above the right horizontal range from 0 to π. Angles below the horizontal range from 0 to $-\pi$. In Excel, once you have calculated the absolute segment angle in radians, you can then determine the angle in degrees with the following command:

= degrees (cell #)

Angle-Angle diagrams
In certain activities, such as locomotion, the motions of the segments are cyclic, in that they are repetitive with the end of one cycle at the beginning of the next. In these instances, an angle-angle diagram may be useful to represent the relationship between two angles during movement.

An angle-angle diagram is the plot of one angle as a function of another angle. That is, one angle is used for the x-axis and one for the y-axis. Typically, one angle is a relative angle and the other is an absolute angle; but diagrams can be made for two relative angles or two absolute angles. For an angle-angle diagram to be meaningful, there should be a functional relationship between the angles. A diagram of elbow angle vs. shank angle will probably not have any value, whereas a diagram of knee angle vs. shank angle will give you some insight into what is contributing to the change in knee angle. A diagram of knee angle vs. hip angle will give you some insight into the coordination of adjacent joints and the muscle groups involved throughout a movement.

One problem with this type of diagram is that time cannot be easily represented on the graph. It can be presented, however, by placing marks on the angle-angle curve to represent each instant in time at which the data were calculated. These marks are placed at equal time intervals and give an indication of the angular distance through which each joint has moved in equal time intervals. Thus, angular velocity of the movement is represented, since the further apart the marks are on the curve, the greater the velocity of the movement. Conversely, the closer together the marks are, the smaller the velocity is.

You can also find the range of motion from angle-angle graphs. Functional range of motion (ROM) is the amount of angular displacement during a task. You can find this by reporting the highest angle and lowest angle of a segment or joint from the graphs.

Total ROM = highest angle - lowest angle

(Reference: Hamill, J, Knutzen, K. Biomechanical Basis of Human Movement. pgs 383-384. 1995)

Laboratory Procedure:

RULES: *Delete excel cells with formulas that refer to empty cells (usually at the bottom of the data), Make sure your angles physically make sense- sometimes excel will give you the "reverse" angle. Also, please graph using scatter plot type with lines connecting the data points! And scale the graph as a square plot with the maximum values on the horizontal and vertical axes being equal. Lastly, make sure your plot axes are at least 18 pt font.*

- Absolute Angles
  Calculate the absolute angles for each frame of the three diving trials you digitized previously. To accomplish this task easily, create a new spreadsheet in Excel to perform all of the calculations.
  1. From the 'Scaled Coordinates' tab in your Back Timer template file, copy the x and y coordinates for the toe, heel, ankle, knee, hip, and c7 (including the headers) into the new spreadsheet, starting in cell C1. Use the 'Paste Special' command to copy the values instead of the formulas.
  2. Fill in column A with the frame numbers and column B with the time (t=0.0s at the 'Depart' event).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Fr #	Time	TOE		HEEL		ANKLE		KNEE		HIP		C7	
2			x	y	x	y	x	Y	x	Y	x	y	x	y
3	1	-2.0												
4	2	=B3+1/30												

	..	O	P	Q	R	S	T	U	V

		Foot Angle (radians)	Foot Angle (degrees)	Shank Angle (radians)	Shank Angle (degrees)	Thigh Angle (radians)	Thigh Angle (degrees)	Trunk Angle (radians)	Trunk Angle (degrees)
1 2									
3		=ATAN2(E3-C3,F3-D3)	=degrees(O3)						

3. In columns O - V, generate the formulas to calculate the **foot**, **shank**, **thigh** and **trunk angles**.

4. This table is a sample spreadsheet. You may have to adjust which cells are referenced in your formula to make sure your calculations are correct. Make sure you understand *why* the formulas work.
5. Once you get the formulas correct for the first frame, copy the formulas into the subsequent rows.
6. Double check your formulas by performing the calculations by hand for one frame. **Go back to the video frames to make sure your angles make sense**.
7. Make two copies of this sheet (so your formulas will copy); one for the Back trial and one for the Reverse trial. Rename the sheets 'Back Timer, 'Back' and 'Reverse' by double-clicking on the tabs and typing in the new names. This will help keep track of what is in each sheet.
8. In the 'Back' sheet, cut and paste your x and y scaled coordinate data from the Back dive on top of the existing "back timer" data portion of your new "back" sheet. All of your angles should be calculated automatically.
9. Repeat step 8 for the Reverse data.

- Relative Angles

  Calculate the relative angles of the ankle, knee, and hip for each frame of the three diving trials you digitized.
  1. Once all necessary segment angles are determined, you can calculate the relative joint angles. For example, to determine the knee angle, the shank and thigh absolute angles must be determined first. Then, the relative knee angle can be calculated from the two segment angles. Refer to Figure 1 above to get the formulas for joint angles. You should be able to generate the necessary formulas in Excel.
  2. The following table is a sample spreadsheet. Add these columns to your Back Timer sheet and fill in the appropriate Excel formulas.

W	X	Y	Z	AA	AB
Ankle Angle (radians)	Ankle Angle (degrees)	Knee Angle (radians)	Knee Angle (degrees)	Hip Angle (radians)	Hip Angle (degrees)
= Q3 + (pi()-O3)	=degrees(W3)				

  3. Copy and paste the **formulas** into the Back and Reverse sheets so that the relative angles are calculated automatically.
  4. For each dive, plot thigh and shank segment angles (y axis) vs. knee joint angle (x axis) *on the same graph* in order to determine segment contributions to joint motion. You should have 3 graphs, one for each trial.
     a. Identify each phase (loading, tip and push) on the graph.
     b. Make sure your data is taking up most of the space on the graph.
     c. Do not plot points after plate departure.
  5. Using the first central difference method (explained in Lab 2), calculate the actual knee angular velocity in radians. Plot knee angular velocity (y axis) vs. knee angle (x axis) for all three dives on one graph.
  6. Create a knee-hip angle-angle diagram by plotting hip angle (y axis) vs. knee angle (x axis).
     a. Identify each phase (loading, tip and push) on the graph.
     b. Make sure the x and y axes have the same range of angles.

c. Do not plot points after plate departure.

Data Analysis and Questions:

1. Display your thigh and shank angle vs knee joint angle graphs.
2. What does the total range of motion tell you about the segments and joint motion (i.e. how does ROM of each segment contribute to the joint ROM)?
3. For each dive, which segment contributed most to the knee joint extension? Explain your reasoning.
4. For each dive, which segment contributed most to the hip joint extension? You do not need to create a graph for this. Explain your reasoning.
5. How can you determine information about angular velocity from your graphs? Based on your knowledge of the dive take-off and your angle-angle diagrams, **discuss** the knee, thigh, and shank angular velocities through each phase of the take-off. (Hint you should have an answer all three.)
6. Display your knee angular velocity vs knee angle graph.
7. Explain in words what your graph shows you. Compare these results to your answer for question 5. Are they the same?
8. Display your knee-hip angle-angle diagram.
9. How are the knee-hip angle-angle diagrams similar/different for the three dives? (Describe in terms of how the joints change).
10. Calculate the knee and hip joint range of motion used during the three dives. Which dive used more hip/knee range of motion? Discuss why you think this might be the case.
11. What information does the knee-hip angle-angle diagram provide with respect to adjacent joints?
12. What is your hypothesis about how the pattern shown in the knee-hip angle-angle diagram is related to the role of one-joint and two-joint muscles crossing the hip and/or knee? Demonstrate your knowledge of the role of different types of muscles.