Name ____________________________

KIN 335 - Biomechanics

LAB: Projectile Motion

Introduction: Performance in many sport activities is dependent on the ability to either control or predict the motion of a projectile. In attempting to produce a particular trajectory of a projectile, we have the ability to manipulate three basic characteristics of the projectile at the instant it is released into the air: its speed, the angle at which it is projected, and the height at which it is released above the landing area. Of particular interest in many examples of projectile motion is the horizontal distance traveled by the projectile (i.e., its range). In fact, this represents the performance measure in many sport events (e.g., long jump, shot put). This laboratory focuses on the effect of speed, angle, and height of release on projectile flight. Some of the issues of concern include: a) how does each individual factor affect the horizontal distance of the projectile, b) how sensitive is horizontal distance to each of these factors, and c) what interrelationships exist among these factors.

In the absence of air resistance, both the vertical and horizontal components of a projectile's motion represent uniformly accelerated motion (i.e., constant acceleration). In the case of the vertical component, the constant acceleration equals that produced by gravity (–9.8 m/s^2). Because gravity affects only the vertical motion, horizontal acceleration equals zero (remember again that this assumes that air resistance effects can be ignored). The equations of uniformly accelerated motion that allow us to predict characteristics of a projectile's flight include:

$$v_f = v_i + at \qquad (1)$$

$$d = v_i t + \tfrac{1}{2}at^2 \qquad (2)$$

$$v_f^2 = v_i^2 + 2ad \qquad (3)$$

where $\mathbf{v_i}$ and $\mathbf{v_f}$ represent initial and final velocities for a time period **t**, **a** equals the constant acceleration, and **d** represents the displacement. **These equations can be applied to either the vertical or horizontal components of a projectile's flight**. When applied to the horizontal motion (i.e., a = 0), equations 1 and 3 simply indicate that the horizontal velocity at the end of the projectile's flight equals that produced at the beginning of its flight (i.e., $v_f = v_i$). Equation 2, when applied to the horizontal component, reduces to:

$$d = v_i t$$

This can be written more specifically to reflect a focus on horizontal motion:

$$d_h = v_h t_{tot} \qquad (4)$$

where $\mathbf{d_h}$ is the range or horizontal displacement of the projectile, $\mathbf{v_h}$ is the horizontal component of velocity at release (and at any other time during the projectile's flight), and $\mathbf{t_{tot}}$ is the total time of flight ($\mathbf{t_{up} + t_{down}}$).

Purpose: To examine the association between a projectile's initial flight conditions (i.e., speed, angle, and height of release) and the resulting motion (i.e., vertical and horizontal speed, horizontal distance, and time of flight) with particular relevance to throwing and the shot put.

Exercises

Part 1--Throwing for maximal height or distance

Each student will complete two throws by bouncing a tennis ball off the floor and into the air. For the first throw, the student should attempt to maximize the vertical height to which the ball travels. For the second throw, the student should try to maximize the horizontal distance the ball travels (i.e., maximize the range).

Note: Try to throw the ball down with the same amount of force for each condition.

For each throw, the following data should be recorded:

1. The total horizontal distance, $\mathbf{d_h}$, traveled by the ball in the air (measured as the straight-line distance between the first two points of contact with the ground).
2. The total time, $\mathbf{t_{tot}}$, the ball spent in the air (i.e., the flight time).

Fill out the chart below with the data collected from each throw and calculate the other variables using the equations of uniformly accelerated motion.

Throw	**Horizontal distance d_h**	**Total time of flight t_{tot}**	**Vertical velocity (i) v_i**	**Horizontal velocity v_h**	**Resultant velocity v_r**	**Vertical distance d_v**	**Angle of release θ**
Max Height							
Max Range							

Show your work here

Questions to answered:

1. How did you change your throwing technique (indicated by the manner in which you threw the ball) between the throw for maximum height versus maximal range?

2. Looking at the data presented in table above, what could you have done to improve your performance for each of the conditions?

Part 2--Sensitivity of performance to speed, angle, and height: Use the computer program PROJEC1 to determine the effect of 10% increases in the speed, angle, and height of release on a projectile's flight.

	Release conditions			Flight results			
	speed	angle	height	v_v	v_h	t_{tot}	d_h
nominal case	10 m/s	38 deg	2.0 m	______	______	______	______
+10% speed	11 m/s	38 deg	2.0 m	______	______	______	______
+10% angle	10 m/s	41.8 deg	2.0 m	______	______	______	______
+10% height	10 m/s	38 deg	2.2 m	______	______	______	______

Compute the percent change in horizontal distance of the projectile for each of the three 10% manipulations compared with the nominal case:

i.e., [(10% condition – nominal case) / nominal case] · 100%

+10% speed________ +10% angle________ +10% height________

Show your work here

Questions to be answered:

3. a) To which of the three release factors was horizontal distance most sensitive? b) Considering the second equation of uniformly accelerated motion expressed specifically for horizontal distance ($d_h = v_h t_{tot}$), are these results as you would expect? Explain.

4. Look carefully at the changes that occurred in vertical speed, horizontal speed, and total time of flight with each manipulation. Are these changes as you would expect? Describe and explain.

Part 3--The case of the maturing shot putter: Factors that affect the optimal angle of release in the shot put for various speeds and heights of release should be important concerns when coaching athletes of various heights and muscular strengths and when designing equipment for use by athletes of different age and physical maturity. Use computer program PROJEC2 to determine the optimal angle of projection and the corresponding horizontal displacement (d_h) under the following conditions:

A. Different strength (reflected by speed) only (using the same shot)

	speed	height	opt.	d_h
"strong"	12 m/s	2.1 m	______	______
"medium"	8 m/s	2.1 m	______	______
"weak"	4 m/s	2.1 m	______	______

B. Different strength and body height (using the same shot)

"tall"	12 m/s	2.1 m	______	______
"medium"	8 m/s	1.9 m	______	______
"short"	4 m/s	1.7 m	______	______

C. Now, let the "weak/short" athlete use a lighter shot (thus, higher speed)

	8 m/s	1.7 m	______	______

Questions to be answered:

5. a) Based on your results, describe how strength (reflected by the ability to generate a given speed of release) affects optimal technique? b) Describe and explain whether technique was affected additionally by the height factor.

Part 4--"The Real Thing": the collision between theory and reality: Using PROJEC1 again, predict flight characteristics for the following videotaped shot put performances by "Dingo" Donovan during which angle of release was changed:

Release conditions			Flight results			
speed	angle	height	v_v	v_h	t_{tot}	d_h
7.38m/s	20.4 deg	1.87m	______	______	______	______
6.44m/s	29.6 deg	2.08m	______	______	______	______
5.93m/s	35.9 deg	2.22m	______	______	______	______
5.35m/s	44.1 deg	2.35m	______	______	______	______

Questions to be answered:

6. What happened to the speed and height of release as the angle of release was increased? Were these changes what you would expect to observe? Explain.

Assignment: Tabulate all data and complete all of the required calculations. Be sure to show your work. If you need to use additional paper, be sure to *organize and present your work clearly*. In addition, provide type-written answers to each of the 6 questions that were asked throughout the lab. Please be complete in your answers to these questions. This assignment is worth 10 points and is due at the beginning of the period Wed., October 1. Assignments that are not stapled at the time they are to be turned in will be considered one day late.

What to hand in:

- Completed lab showing all calculations for Parts 1 and 2.
- Type-written answers to questions 1-6.