Free Fall

Equipment

- A paper or small bunder clip
- A ball (tennis or golf, or baseball, or fetching ball, or gum ball)
- Stopwatch (use phone or https://www.online-stopwatch.com/full-screen-stopwatch/)
- Soft Pad for landing if necessary

Objectives

- *To measure the time of a fall for different objects*

Introduction

Galileo was the first to describe gravity on Earth's surface correctly. Through experiments, he found that, neglecting air resistance, any object falls with a constant acceleration, $g = 9.8\ \mathrm{m/s^2}$ downward. That means that if the object is dropped from rest, it will travel distance

$$\mathrm{h} = \frac{1}{2} g t^2 \qquad (1)$$

The value of $9.8\ \mathrm{m/s^2}$ implies that any object would travel 4.9 meters in the first second of drop. Such rapid motion makes even a small uncertainty of 0.1 second relatively large unless the object travels a very long distance. For example, in a common laboratory setting where height does not exceed 2 meters, the time of travel will not exceed 0.64 second. Taking in consideration that typical absolute uncertainty due to human reaction ranges between 0.1s and 0.2 s, an experiment in a common laboratory setting yields at least 17% uncertainty. The same absolute uncertainty will produce much smaller relative uncertainty at larger distance of travel. Increasing a height of drop to 5 meters will increase the time of travel to 1 second and reduce the relative uncertainty to 10%. However, if such increase in distance is not possible, a decrease in absolute uncertainty could solve the problem. Due to high sensitivity, electronic sensors produce much smaller absolute uncertainty that aids in avoiding large relative uncertainty in experiments that incorporate small heights.

Part #1: Humans vs. Robots

In this part you will determine your reaction time in two different ways: by using a software and by directly reacting to a fall of a ruler.

1. Open Reaction Time test from Human benchmark site:
https://humanbenchmark.com/tests/reactiontime
2. Complete the test and record each reaction time in Table 1 (***convert milliseconds to seconds***).
3. In one hand, hold a ruler down vertically by the **30cm** mark. Place fingers of the other hand around **0cm** mark of the ruler. It is recommended to use a dominant hand to hold the ruler.
4. Drop the ruler from one hand to catch it with the other. See Figure 1.
5. Note how far from "0" the ruler was caught and record this distance.

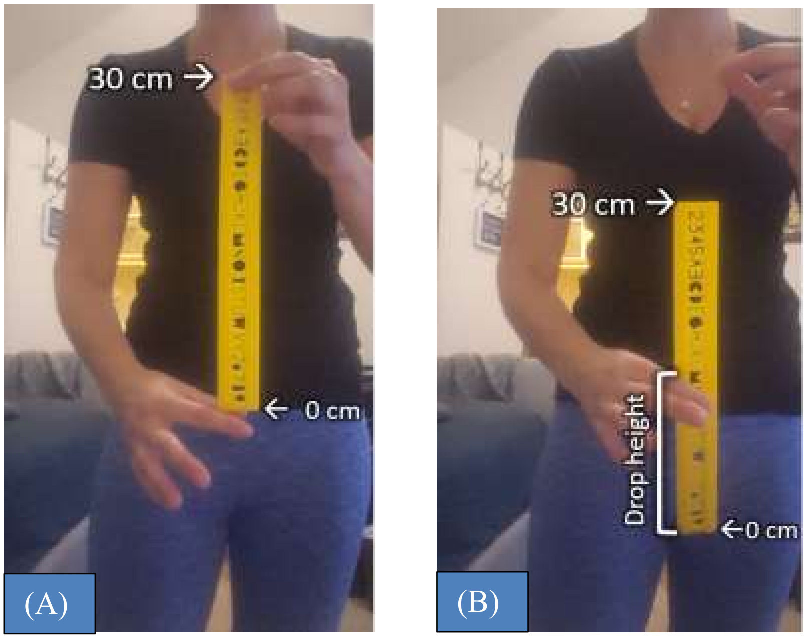

Figure 1: (A) Holding the ruler before the dropping it (B) Catching the ruler after it is

6. During the time it took you to react, the ruler was in the air and fell down the distance, h, at which you caught it. Use the relationship h = $4.9t^2$ to solve for the time (your reaction time). *The value of h used in calculation must be in meters (with a 30cm ruler it is not possible to get a reaction time greater than 0.25s. (Hint:* $t = \sqrt{\frac{h}{4.9}}$*)*

6. Drop the ruler 4 more times and average the calculated reaction times.

7. Calculate the Standard Deviation for each method to determine which one is more precise.

8. Calculate % Difference between values obtain by two methods. Which one is more reliable? Why?

Trial #	Obtained from reaction to a drop			Obtained from the software, **s**
	Distance ruler traveled, **cm**	Distance ruler traveled, **m**	Calculated reaction time, **s**	
1				
2				
3				
4				
5				
Average reaction time, seconds				
Standard Deviation, seconds				
% Difference				

Table 1. Data recorded for the determining a reaction time. (The caption must be modified)

Part #2: Timing a Drop

In this part, the time it takes for a ball and a clip to fall from a set of height will be measured by a stopwatch.

1. Place a soft pad on the floor for landing if necessary.
2. Take turns dropping two items, first a ball, then a clip, and record the time it takes each object to reach the ground when dropped from several heights (your knee, tabletop, your shoulders, as high as you can each).
3. Use a stopwatch to record the time of the fall.
4. Repeat the drop for at least 5 trials at each height.
5. Average the values of drop time and calculate the standard deviation.
6. Plot the data as a bar diagram ***Average time*** vs. ***Height*** for each object. Plot two series on the same chart for comparison. Ask your lab instructor for help with the diagram if needed.
7. Discuss the difference between two plots if any or absence of the difference if none.
8. Plot the data as a bar diagram ***St. Deviation in time*** vs. ***Height*** for each object. Plot two series on the same chart for comparison. Ask your lab instructor for help with the diagram if needed.
9. Discuss the difference between two plots if any or absence of the difference if none.
10. Compare the values of the standard deviations with the reaction time obtained in Part 1.
    Do you observe any trend? Consider that the reaction time was the same for all measurements.

<table>
<tr><th colspan="2" rowspan="2">Height</th><th colspan="2">Knee</th><th colspan="2">Tabletop</th><th colspan="2">Shoulders</th><th colspan="2">Max of reach</th></tr>
<tr><th>Clip</th><th>Ball</th><th>Clip</th><th>Ball</th><th>Clip</th><th>Ball</th><th>Clip</th><th>Ball</th></tr>
<tr><th rowspan="7">Time of Fall (s)</th><th>Trial 1</th><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Trial 2</th><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Trial 3</th><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Trial 4</th><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Trial 5</th><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>Average</th><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>St.Dev.</th><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 2. Data recorded for object drops from various heights. (The caption must be modified)

Requirements for the Report:

1) *Students have an option to submit an individual report but are encouraged to work with assigned lab partners.* ***Only one report needs to be submitted per lab group from the Blackboard page (DO NOT email it to the lab instructor!).*** The names of the lab partners collaborating on the report must be listed in the header on each page of the report; a lab partner whose name is not listed will not receive the credit for the lab ***unless separate report is submitted individually*** (such report will not receive 5 points for the team work).

2) If the report is collaborative, the data presented in the report must consolidate the individual data from each lab partners and include as many versions of both tables and the diagram as names in the header. The tables could be distinguished by sub-labeling (1.1 or 1a, 1.2 or 1b, etc.) with appropriate captions.

3) The report must include an abstract ***of about one page*** summarizing the experience for all parts of the lab. The abstract should not have any emotional descriptions such as "I was frustrated" or "I had fun doing the experiment". Points will be deducted for such irrelevant information or redundancy.

- The **abstract section** must contain the following explanations in paragraph form:
    - How the data was collected in each part including an explanation of the used tools
    - How the data was analyzed including the calculation of reaction time in Part 1 and plotting of the collected data in Part 2
    - A statement based on Table 1 about precision and accuracy of the two methods. Consider that the software used in Part 1 relies on the speed of the browser.
    - A statement based on bar diagrams about the trend in time of drop.
    - A statement about the effect of the reaction time on the measured time of drop at different heights.
- The **data section** must include
    - 2 Tables × Number of collaborators (labeled and captioned)
    - 2 bar diagrams × Number of collaborators (labeled and captioned)