EXPERIMENT: REACTION TIME

OBJECTIVES   1) To make a series of measurements of your reaction time.

2) To make a histogram (distribution curve) of your measured reaction times.

3) To calculate the "average" or "mean" of these reaction measurements as a "best value".

4) To calculate the "standard deviation" (uncertainty) associated with an individual measurement.

5) To calculate the "standard deviation" associated with the mean value.

6) To compare your calculations with the data displayed on the histogram, and the prediction from the "normal" distribution.

7) To discuss the significance of data comparison when the spread in values is large.

THEORY

Two of the main purposes of this experiment are to familiarize the student with the taking of experimental data and with the reduction of such data into a useful and quantitative form.

In any experiment, one is concerned with the measurement of some physical quantity. In this particular experiment it will be your individual reaction time. When you make repeated measurements of a quantity you will find that your measurements are not all the same but vary over some range of numerical values. In general the wider the spread of the measurements, the poorer the reliability or precision of the measured quantity. If the measured quantity is to be of any use in further work, or to other people, it must be capable of being described in simple terms. One of the most valuable methods to picture measured values of a single quantity is to create a "histogram." The histogram is a diagram drawn by dividing the original set of measurements into intervals (called Bins) of predetermined magnitude and counting the number of measurements within each interval. One then plots the frequency (the number of times each value occurs) versus the values themselves. The histogram has the advantage of visually presenting the distribution of readings or measurements. If the number of readings is very high and the bins are small, the histogram approaches a continuous curve and is called a "distribution curve." Figure 1 shows a typical histogram for a set of observations. When putting the values into bins, systematically put values which occur on the bin limits into the next higher bin.

The histogram, however, has the disadvantage that it does not tell one which single number is the answer, or how reliable it is. It will therefore be necessary to define quantities which will indicate the "best" value and the associated "uncertainty."
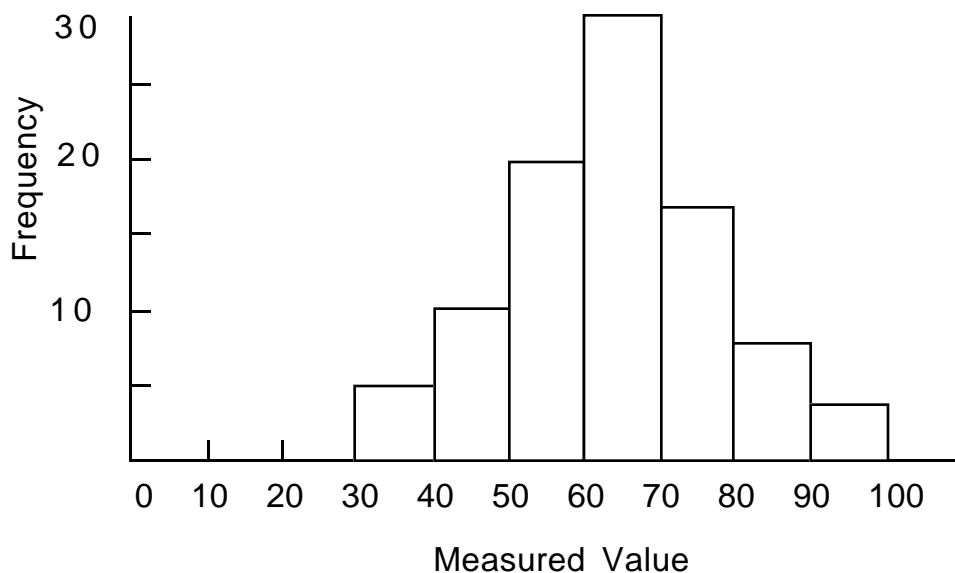
TYPICAL HISTOGRAM (bin size = 10)
Figure 1

From an intuitive approach one might say that the best value is somehow related to the middle of the distribution, while the uncertainty is related to the spread of the distribution. The following formulas, which we will define, will in general only have significance for symmetrical distributions. Using mathematical statistical theory it turns out that the best value is nothing more than the average of our measurements, which we will denote with the symbol $\bar{x}$.

$$\text{Best Value (Average) } = \bar{x} = \frac{\sum x_i}{N}$$

where

$$\sum x_i = x_1 + x_2 + x_3 + ... + x_N$$

N = Total Number of Measurements
x_1 = Value of the 1st Measurement, etc.

We now need to define a quantity that is connected with the width of the distribution curve. This quantity is associated with the deviations of the individual readings from some central (average) value on the distribution curve. This quantity is commonly called the variance and is defined as follows:

$$\text{Variance } = \frac{\sum (x_i - \bar{x})^2}{N-1}$$

where

$$\sum (x_i - \bar{x})^2 = (x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + ...$$

The quantity that we will associate with the uncertainty of a single measurement is called the "standard deviation" (denoted by "s") and is simply the square root of the variance.

$$s = (Variance)^{1/2}$$

We are also interested in the uncertainty in $\bar{x}$. That is, by how much $\bar{x}$, calculated for different sets of data, are likely to deviate from each other. This uncertainty is characterized by s_m, the width of the experimental distribution of values of $\bar{x}$ or "Standard Deviation of the Mean" which is calculated by

$$s_m = \frac{s}{\sqrt{N}}$$

Note that <u>the larger the number of measurements made of a quantity by an experimenter the smaller the random uncertainty associated with the "best" or mean value</u>.

Many theoretical distribution curves have been defined and their properties evaluated, but the one which is most significant in the theory of measurement is the Gaussian or "Normal" distribution. If all the experimental data, which You have obtained, correspond to one and the same physical quantity, then for very large number of measurements they will be described by the Gaussian distribution with the peak at the average value $\bar{x}$.
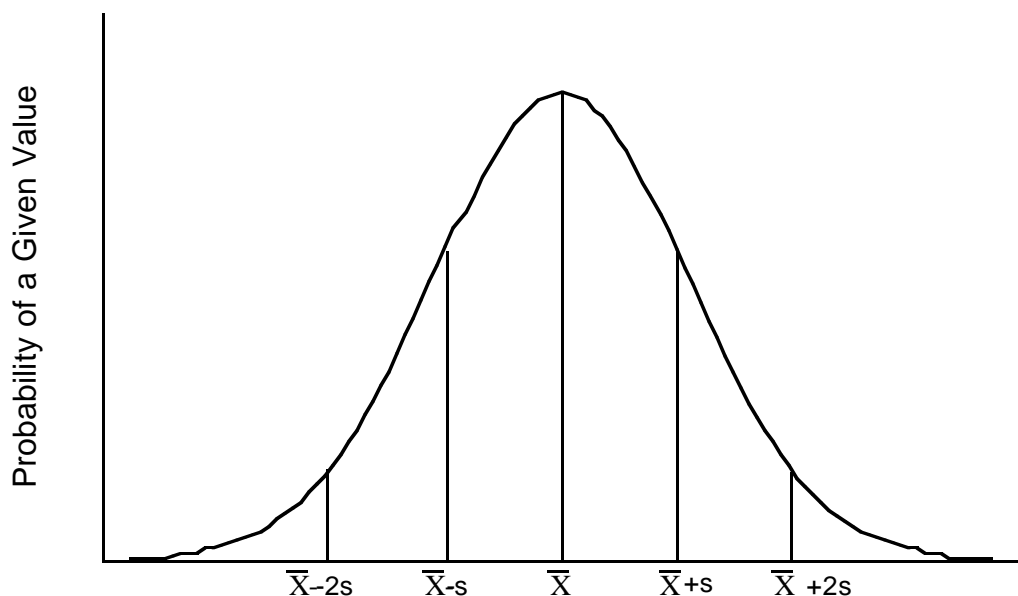
GAUSSIAN DISTRIBUTION CURVE
Figure 2

Some of the properties of this distribution are that it is symmetric around a peak value and falls to zero on either side of the peak, giving it a "bell shaped" appearance. We use the Greek letter σ to represent the standard deviation when referring to a Gaussian distribution and "s" for the standard deviation calculated from finite sets of observations. ("s" is the best estimate of σ for a finite set of observations.) When considering Gaussian distributions the area enclosed by $\pm\sigma$ around the peak will contain 68% of the area of the

curve (or 68% of the measurements). This means that an individual measurement has a 68% chance of falling within a region $\pm\sigma$ around the peak or "mean" value of the distribution. An area bounded by $\pm 2\sigma$ will contain 95% of the area of the curve and therefore represent a 95% chance that an individual measurement will fall within this region of the distribution. This is illustrated in Figure 2.

PROCEDURE

One member of the group will "secretly" start the digital timer with a remote switch. The subject will use the stop switch to halt the timer as fast as the reflexes permit. Record the reaction time and reset the timer for the next run.   Make at least 10 practice runs before recording any data. Record 25 measurements of the reaction time.

Record the values for reaction time in the empty spreadsheet in the *Reaction_time* folder. Save as Rxn_time_your name/partner. Save in your section folder in the folder on the desktop.

1.   For the data compute $\overline{X}$, s, s_m for five measurements, i.e., 1-5, and fill in the correct areas on the spreadsheet.   For the N=5 case do the calculations once by hand and show all your work on a separate sheet of paper. Then redo them using the spreadsheet and compare the results.

   To fill in the spreadsheet, use the same steps as in the introductory lab. First, type the 25 values of the reaction times into the blue area. After that You will be able to calculate the mean value for the first 5 measurements. Go to the corresponding cell (C22) and type "=" to go to the mathematical mode. Enter the formula for the mean value from the theoretical section of the manual. Always refer to the cells by their coordinates and not by the numbers which they contain. To sum the first five values of the measured reaction times, use the built-in ***Excel*** function SUM(First coordinate: Last coordinate). For instance, to sum the first 5 numbers in the column, type "=SUM(B15:B19)". Click "Enter" to finish the formula.

   The second and third columns in the spreadsheet are used to calculate the standard deviation for N=5. To fill them in, type the formula into the first cell, then highlight it, copy it to the clipboard (⌘-**C**), highlight the rest of the column and paste (⌘-**V**).

   In Your calculations You will have to refer to the cell with the already calculated value of average. However, You can't simply type in the coordinate of the cell, which contains this value. If You do this, Excel will automatically increment the value of the coordinate when You "copy and paste" the formula to the lower cells. For example, if You enter the coordinate of the cell with the average as "C22" in the first row, it will be substituted for "C23", "C24" and so on when copied into the lower rows. To avoid this, let's give a unique name to the cell with the average. Type this name (for instance, "mean5") in the small window in the upper left corner, instead of its coordinate C22. Hit "Return": the coordinate in the window will be substituted for "mean5". You can now use this name in all the calculations; all the formulas of the spreadsheet will refer right to this particular cell.

2.   Repeat the calculations in the spreadsheet to find $\overline{X}$, s, s_m for N = 1-10 and N = 1-25.

3. Using **Kaleidagraph** plot a histogram of the 25 measurements using a convenient bin size, <u>not less than 25% of the standard deviation(s)</u>. Clearly mark $\overline{X}, \overline{X} \pm s, \overline{X} \pm 2s$, and $\overline{X} \pm s_m$ on the histogram.

   - To do this you need to transfer your data by copying and pasting from **Excel** to **Kaleidagraph**. Once this is done, select *Gallery*, *Stat* and finally *Stack Histogram* from the pull down menus.

   - You can change the number of bins by using *Histogram Options* under the *Format* menu.

4. Determine the actual percentage of all 25 measurements which lie between $\overline{X} \pm s$ and $\overline{X} \pm 2s$. Do your results differ from those expected for a pure Gaussian distribution?

5. Compare your results with those of other students and discuss whether the differences are significant[*] or not.
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QUESTIONS

1) If you had one measurement which was $\overline{X} + 1000s$, the probability that this measurement is from the same distribution as the others is much less than 10^{-9} or 1 in a billion, what should you do? What must have happened during this measurement?

2) How many measurements of reaction time would you have to take to reduce by a factor of two the standard deviation of the mean (s_m) for the data in step 2?

3) Two red blood cell counts are I. $(4.53 \pm .07)$ x 10^6 cells/cm^3 and II. $(4.84 \pm .28)$ x 10^6 cells/cm^3. Is the probability reasonably good or very bad (choose one and justify) that these measurements are from the same human? (Evaluate the difference and comment.)

CHECKLIST

Your report should include:
1) The manual calculations for the first five measurements
2) The filled spreadsheet
3) The histogram and its analysis (as in the items 4 and 5 of the procedure)
4) Answers to the questions

Don't forget to take the manual for the next experiment before you leave!!

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[*] A significant difference exists if the two mean values differ by much more than the uncertainty in the difference (σ_{diff}); using our simplified method this is just the sum of the associated standard deviations. Remember that a normal distribution predicts that 32% of the measurements will differ by greater than 1 σ_{diff} and 5% will differ by greater than 2 σ_{diff}.

Reaction Time_new

Partner:					Name:
					Section:
	KEY:				
	Fill in blue areas with measured quantities				
	Fill in yellow areas with calculated quantities				
	Values in purple are used for computing your final results				
		N=5	N=5	N=10	N=25
Number	Time [sec]				
	X_i	$(X_i - mean)$	$(X_i - mean)^2$	$(X_i - mean)^2$	$(X_i - mean)^2$
1					
2					
3					
4					
5					
6					
7		Mean for N=5			
8		(your value)			
9		Standard deviation (s)			
10		(your value)			
11		Standard deviation of mean (sm)			
12		(your value)			
13				Mean	
14					
15				Stand. Dev. (s)	
16					
17				Sm	
18					
19					
20					
21					
22					
23					
24					
25					
					Mean
					Stand. Dev.
					Sm