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## Right Place, Wrong Time

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It's important to check the results from an experiment. Does the result make sense? Does it follow from other facts that are known? From the standpoint of teaching High School science, checking if one's results are sensible adds an additional layer of safety that the results are correct. (From the standpoint of advancements in Science, a basic research tenet is that results must be repeatable and not just a fluke. Professional scientists were occasionally discredited when their data can't be replicated; usually, they have made some blunder, but in rare instances, it turns out some aspects of their data has been faked.)

The following story can be used to teach that results must be checked against known facts to see if they're reasonable. It is designed to be a follow up to the PUMAS example "The Fall of the Ruler." Some of the background information in that example is repeated here for ease of understanding.

### Human Reaction Time [RT] Background

Human Reaction Time [RT] is defined as the time it takes a Human (you!) to react to an event such as a light or a sound. Reaction Times come into play during emergencies ("Quick! A cow is on the tracks! Stop the train!") and more ordinary events, such as stopping at a stop light, answering a ringing phone, turning to face someone who's talking to you. [For additional background, see the PUMAS example: "The Fall of the Ruler."]

You can measure human RTs using a simple ruler that has been calibrated in milliseconds (msec), rather than inches or meters. Gravity causes objects to drop towards Earth. The acceleration due to gravity is incorporated in the equation relating distance to time:

$$D = 0.5 * A * T^2$$

where A is approximately 10 meters / second<sup>2</sup>, T is time in seconds, and D is distance in meters.

Thus, a ruler drops this distance in 1 second:

$$D = 0.5 * 10 * (1)^2 = 5 \text{ m (about 200 inches)}$$

and in 0.1 second (100 msec), the distance in meters is

$$D = 0.5 * 10 * (0.1)^2 = 0.5 * 10 * 0.01 = 0.05 \text{ meters (about 2 inches)}$$

### Checking One's Results: Not Even School-Grade Materials are Safe

When I was in graduate school, I helped my professor revise an "Introduction to Psychology" class, in which students were taught how to run and analyze experiments.

In a teaching-supplies catalog, the professor found a plastic ruler for measuring human RT. The ruler eventually formed the basis for one of the classes, essentially the second activity described in the PUMAS example "The Fall of the Ruler". However, in testing the ruler, I repeatedly got RTs that were *too* good. From classic experiments, we knew that human RTs are typically indicated as 180 msec or longer, but these results were sometimes as small as 130 msec. I was known as a quick person, but getting an RT measurement 30% better than human capability was *very* suspicious. We checked the equation relating time and distance and found the ruler was wrong! By looking at the marks on the incorrect ruler, we were able to figure out the manufacturer's error.

I was stopping the ruler after a 7 inch drop. Using the time-distance equations above, that indicates an RT of about 190 msec. The incorrect ruler marked 7 inches as a reaction time of 135 msec. We tried to determine the manufacturer's error in two ways. They might have left off the square of the time factor, giving an incorrect equation for distance:

$$D = 0.5 * A * T$$

That would have left a linear relation between distance and time. But, the marks on the ruler did get further apart for longer distances. (All objects drop towards the ground faster with time - in one-tenth of a second the ruler drops 2 inches, but in one second, it doesn't drop 10 times further, but 100 times more). Because the ruler had time marks spaced by variable amounts, we suspected the manufacturer's equation included the square of T.

Next we asked what would happen if the manufacturer had mistakenly removed the factor of 0.5:

$$D = A * T^2$$

This equation puts the mark for 100 msecs (0.1 sec) around four inches:

$$D = 10 * 0.1^2 = 10 * 0.01 = 0.1 \text{ meters (approximately 3.9 inches).}$$

The values from this equation matched the marks on the defective ruler: Four inches was marked as 100 msec, and "my" RT distance (7 inches) was marked between 130-140 msec. Thus, we determined what a correctly marked "time ruler" should have had, and we also discovered the error in the equation used by the ruler maker. We were amazed that a teaching device, manufactured in the thousands and sold nationally to schools, would have such a fundamental error. Evidently, the manufacturer had not checked their results.

### **Suggested Activities**

As a follow up to activities in The Fall of the Ruler, you can:

1) Construct a ruler based on the erroneous equation, and have students collect RTs and show them to be better than published reports of human RTs. Then ask students to see if they can identify the error responsible for your defective ruler's markings.

Shorter activities using this example could be:

- 2) Relate the story, asking students to try out different equations and determine what the error was;
- 3) Relate the story, asking students to compare time plots for a "good" and "defective" time rulers;

## Lessons to learn

1) Whenever possible, check that your results are "reasonable," especially if you can find prior knowledge that is similar to your result. In our case, we knew from carefully run prior experiments that "reasonable" RTs couldn't be less than 150 msec.

2) When using equations, it isn't enough to get the functional form right, in this case:  $D=AT^2$ . You also need to get the coefficients right. The manufacturer's equation was missing the factor of 0.5, which made the RT measurements off by the square root of 2.

Below is a table of the relationship between time (in msec) and distance, both for a correct-time ruler and for the defective time ruler. [In this table, we've used a more exact figure for gravity, 9.8 meters per second squared]. You can see that both rulers would have "marks" at about 11.1 inches. The correct ruler says that's an RT of 240 msec, whereas the incorrect one says it is a RT of 170 msec.  $240/170 = 1.41$ , or the square root of 2.

Time (msec)	Distance (meters)	Distance (inches)	Wrong Distance (meters)	Wrong Distance (inches)
50	0.012	0.482	0.025	0.965
60	0.018	0.694	0.035	1.389
70	0.024	0.945	0.048	1.891
80	0.031	1.235	0.063	2.469
90	0.040	1.563	0.079	3.125
100	0.049	1.929	0.098	3.858
110	0.059	2.334	0.119	4.669
120	0.071	2.778	0.141	5.556
130	0.083	3.260	0.166	6.520
140	0.096	3.781	0.192	7.562
150	0.110	4.341	0.221	8.681
160	0.125	4.939	0.251	9.877
170	0.142	5.575	0.283	11.150
180	0.159	6.250	0.318	12.501
190	0.177	6.964	0.354	13.928
200	0.196	7.717	0.392	15.433
210	0.216	8.507	0.432	17.015
220	0.237	9.337	0.474	18.674
230	0.259	10.205	0.518	20.410
240	0.282	11.112	0.564	22.224
250	0.306	12.057	0.613	24.114

The author thanks Ron Menendez and Chuck Watson for their help in preparing this example. The author's academic background is in Experimental Psychology, having done fundamental research in how the auditory system processes complex sounds. His proudest moment as a graduate student wasn't getting an inhumanly small Reaction Time, but testing a major symphony orchestra for its frequency perception. The only prior study (75 years earlier!) of orchestra musicians was of the Vienna Court Orchestra and included Gustav Mahler as a listener. The author's current work involves speech technology for telecommunication services.