National Aeronautics and Space Administration

MATH AND SCIENCE @ WORK
AP* STATISTICS Educator Edition

MAINTAINING BONE MINERAL DENSITY

Instructional Objectives
Students will
- construct a null and alternative hypothesis to compare the effectiveness of two countermeasures for maintaining bone density during prolonged space missions;
- choose an appropriate hypothesis test;
- check assumptions necessary to conduct the hypothesis test;
- perform the hypothesis test; and
- draw the correct conclusion based on the results of the test.

Degree of Difficulty
For the average AP Statistics student, this problem is moderately difficult.

Class Time Required
This problem requires 30-45 minutes.
- Introduction: 5-10 minutes
- Student Work Time: 15-20 minutes
- Post Discussion: 10-15 minutes

Media Resources
A video, *How Space Exploration Affects Astronauts' Bones* (2:16), is accessible at the provided link. It may help students better engage with this topic either before or after they read the background section.

http://www.nasa.gov/multimedia/videogallery/index.html?media_id=14387949

Background
This problem is part of a series of problems that apply Math and Science @ Work in NASA's scientific laboratories.

The Biostatistics Laboratory (BSL) is one of several research laboratories within the Human Adaptation and Countermeasures Division which supports the Human Research Program at NASA Johnson Space Center in Houston, Texas. This laboratory provides statistical consulting in the application of statistical theory and practice to ongoing biomedical research. Lab personnel often aid in the preparation of research proposals that

Grade Level
10-12

Key Topic
Hypothesis tests

Degree of Difficulty
Moderate

Teacher Prep Time
10 minutes

Class Time Required
30-45 minutes

Technology
- Statistical graphing technology
- Projector
- Movie player

AP Course Topics
Statistical Inference
- Tests of Significance
Exploring Data
- Constructing and interpreting graphical displays of distributions of univariate data

NCTM Standards
Data Analysis and Probability

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describe the experimental design, statistical modeling, and subsequent analysis of anticipated research data. Once data is gathered, statisticians can also assist with analysis and interpretation of results to help the investigators extract the most information consistent with the goal of maintaining statistical integrity. The Biostatistics Laboratory also provides opportunities for undergraduate students to be directly involved in the analysis and interpretation of biomedical research at NASA.

One area in which the Biostatistics Laboratory contributes to NASA's Human Research Program is in the interpretation of astronauts' bone mineral density (BMD) data during long-duration spaceflights (typically of four to six months). A shift in gravitational environment causes changes in their bodies, including the loss of BMD. This is of specific concern for astronauts' health, especially when they return to Earth's gravity.

On Earth, a person's skeletal BMD peaks around the age of 30. After the age of 35, BMD of certain skeletal sites decreases, on average, by < 1% each year. However an astronaut's BMD at those same sites can decrease by an average of 1 to 2% per month while living in space, even though he or she exercises and is otherwise a healthy individual. This weakening of the astronauts' bones is, in a way, similar to osteoporosis. With this condition, bones lose minerals (especially calcium) which make the bones weaker, more brittle, and more susceptible to fractures.
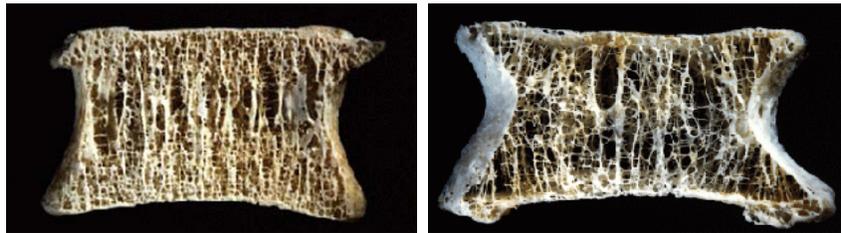

Figure 1: Normal bone compared to osteoporotic bone.
(Source: Mosekilde, L. Z rheumatol 2000; 59: Suppl 1:1-9)

In order for astronauts to best maintain bone health while in space and after returning to Earth, interventions (countermeasures) are prescribed. Exercise is the primary countermeasure used during spaceflight to help astronauts maintain BMD. The U.S. Space Station Skylab (in operation from 1973 to 1979), the Russian Space Station Mir (in operation from 1986 to 2001), and the International Space Station (ISS) (in operation from 1998 to present) all made use of various treadmills and a bicycle ergometer. In an effort to improve the effect of the exercise countermeasures, astronauts started using resistive exercise. The Interim Resistive Exercise Device (iRED), which used an adjustable cable to provide a measured amount of resistance, was installed on the ISS in late 2000.

Figure 2: Left to right: Charles "Pete" Conrad on the bicycle ergometer aboard the Skylab, Shannon Lucid on a treadmill aboard the Mir, Edward T. Lu using the iRED on the ISS, and Robert Thursk using the ARED on the ISS.

In early 2009, the iRED was replaced by the Advanced Resistive Exercise Device (ARED), which uses two piston/cylinder assemblies which provide a constant load to simulate the use of free weights. As new exercise equipment and other countermeasures are implemented, NASA researchers and statisticians continue to assess the effect of these countermeasures on astronauts' health.

AP Course Topics

Statistical Inference: Estimating population parameters and testing hypotheses

- Tests of significance
  - Logic of significance testing, null and alternative hypothesis; p-values; one- and two-sided tests

Exploring Data: Describing patterns and departures from patterns

- Constructing and interpreting graphical displays of distributions of univariate data (dotplot, stemplot, histogram, cumulative frequency plot)
  - Outliers and other unusual features
  - Shape

NCTM Standards

Data Analysis and Probability

- Select and use appropriate statistical methods to analyze data
- Develop and evaluate inferences and predictions that are based on data

Problem and Solution Key (One Approach)

Exercise during spaceflight has been used as a countermeasure to inhibit loss of bone mineral density (BMD). One research study performed by the Biostatistics Laboratory compared the differences in BMDs of astronauts from post-flight to pre-flight aboard Mir (using a treadmill and bicycle ergometer) and of astronauts aboard the ISS (using the iRED). These data are found in Table 1 (page 4).

Is using the iRED exercise method significantly better than using the treadmill and bicycle in maintaining bone density?

Perform an appropriate test to determine the answer to this question. Add appropriate TI-Nspire pages (notes, data and statistics, and calculator) in order to give a complete answer to the problem.

Component 1: State a correct pair of hypotheses.

H_0: $\mu_{iRED} = \mu_{tread}$ or $\mu_{tread} - \mu_{iRED} = 0$
On average, using the iRED exercise device is the same as using the treadmill and bicycle ergometer in mitigating bone loss.

H_a: $\mu_{iRED} > \mu_{tread}$ or $\mu_{tread} - \mu_{iRED} < 0$
On average, using the iRED exercise device is better than using the treadmill and bicycle ergometer in mitigating bone loss.

Component 2: Identify a correct test (by name or formula). State and test the assumptions.

Use a one-tailed, 2-sample t-test comparing means, setting alpha to reject the null hypothesis $= 0.05$.

The graphs show a roughly normal distribution with no outliers or extreme skewness and the normal probability plots are linear, so it seems reasonable to proceed with a t-test.

Note: A two-tailed hypothesis pair and two-tailed 2-sample t-test could also be justified if the student claims that we don't know a-priori that the iRED is an improvement over the devices used on Mir.

Table 1: Differences in BMDs (tested at the femoral greater trochanter) from post-flight to pre-flight of astronauts using different exercise methods

The screenshots below show a normal probability plot, histogram, and boxplot of the treadmill & bicycle data and of the iRED data.

Treadmill & Bicycle	iRED
-0.072	-0.07
-0.035	-0.050
-0.128	-0.034
-0.139	-0.033
-0.067	-0.030
-0.120	-0.019
-0.106	-0.018
-0.124	-0.085
-0.114	-0.014
-0.066	-0.010
-0.060	-0.038
-0.113	-0.023
	0.020
	-0.085
	-0.071
	-0.015
	-0.036
	0.004
	-0.101
	-0.052
	-0.036
	-0.067
	-0.062
	-0.105
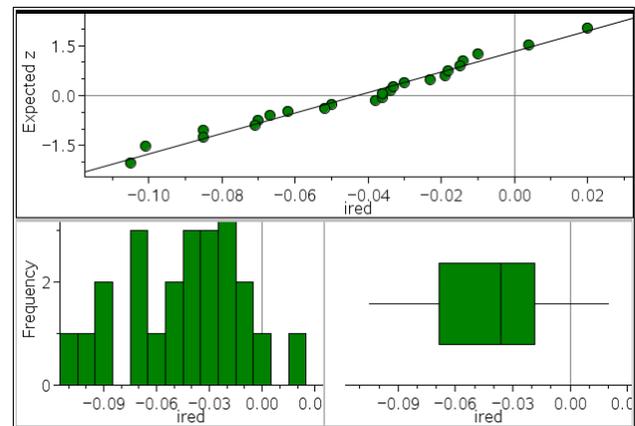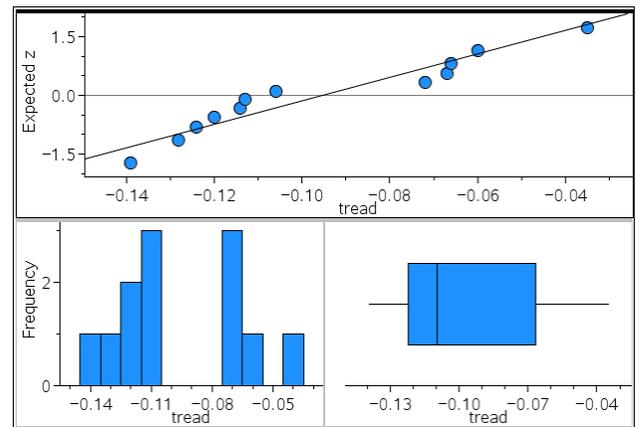
Component 3: Perform correct mechanics, which includes the value of the test statistic and p-value (or rejection region).

The test results are as follows:

$t = -4.47861$

$p = 0.000098$

$df = 21.5611$

Component 4: Draw an appropriate conclusion in context and with linkage to the *p*-value (or rejection region).

Since the p-value is so small (< 0.0001), we reject H_0 and conclude that using iRED was significantly better at maintaining BMD during long-duration spaceflight than using just the treadmill and bicycle.

Note to educator: NASA is concerned that prolonged exposure to microgravity conditions may predispose astronauts to fracture under lower loads than previously tolerated or to aging-related fractures at a younger age. For NASA to address these clinical risks, there is a need to measure a surrogate of bone strength since the most accurate way of measuring bone strength is to measure the force required to fracture a bone. The most widely applied and tested surrogate measure for bone strength is to measure bone mineral density (BMD). The technology used to measure BMD, however, has some limitations that reduce its ability to give a full reflection of bone strength.

Even though NASA's current analysis of BMD provides some encouraging results on the effectiveness of exercise to maintain bone mass, the efficacy of exercise to preserve bone strength is still unsubstantiated. Therefore, it is important to convey to your students that there are multiple factors that influence bone strength, and that measurement of BMD as a reflection of bone loss is only one factor.

Scoring Guide

This question is scored as Essentially Correct (E), Partially Correct (P), or Incorrect (I).

Score	Description
Essentially Correct (E)	All four components are correct.
Partially Correct (P)	Two or three components are correct.
Incorrect (I)	At most one component is correct.

Contributors

This problem was developed by the Human Research Program Education and Outreach (HRPEO) team with the help of NASA subject matter experts and high school AP Statistics instructors.

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