***Lingering Effects of Sleep Deprivation***

***Adapted for use in high school from an activity in Tintle et al.; 2012, John Wiley and Sons***

Many students pull “allnighters” when they have an important exam or a pressing assignment. But can you really function well the next day after a sleepless night? What about several days later: Can you recover from a sleepless night by getting a full night’s sleep on the following nights?

Researchers Stickgold, James, and Hobson investigated this in a study published in *Nature Neuroscience* (2000). Twenty-one volunteers, aged 18 to 25 years, were first trained on a visual discrimination task that involved watching stimuli appear on a computer screen and reporting what was seen. Performance was recorded as the minimum time (in milliseconds) between the appearance of stimuli and an accurate response. Then one group was randomly assigned to be deprived of sleep for 30 hours, followed by two full nights of unrestricted sleep, whereas the other group was allowed to get unrestricted sleep on all three nights. Following this, both groups were retested on the task. Researchers recorded the *improvement* in performance as the decrease in time required at retest compared to training. For example, if someone took 5 ms at the beginning of the study and then 2 ms, at the end, the improvement score is 3 ms. But if someone took 2 ms at the beginning and then 5 ms at the end, the improvement score is -3 ms. The goal is to see whether the improvement scores tend to be higher for the unrestricted sleep treatment then for the sleep deprivation treatment.

Here are the data from the experiment. Positive values indicate better performance at retest than at training, and negative values indicate worse performance at retest than at training:

Unrestricted-sleep group’s improvement scores (milliseconds):

25.2, 14.5, -7.0, 12.6, 34.5, 45.6, 11.6, 18.6, 12.1, 30.5

Sleep-deprived group’s improvement scores (milliseconds):

-10.7, 4.5, 2.2, 21.3, -14.7, -10.7, 9.6, 2.4, 21.8, 7.2, 10.0

1. Construct a dotplot for each of the two experimental groups (unrestricted and deprived). Based on these dotplots alone, which group (unrestricted or deprived) appears to have had the higher average improvement? Explain your thinking?
2. Based on the dotplots alone, which group (unrestricted or deprived) appears to have had more variability in improvement? Explain your thinking.
3. For each group, calculate the values of the mean () and standard deviation (*s*) and record them below.
	1. For the *unrestricted* group, record the sample size (*n*), mean, and standard deviation.

*nunrestricted* = $\overbar{x}$unrestricted = *s*unrestricted =

* 1. For the *deprived* group, record the sample size (*n*), mean, and standard deviation.

*ndeprived*= $\overbar{x}$ deprived= *s*deprived =

1. Based on the numerical summaries reported in #3, which group (unrestricted or deprived) had the higher average improvement?
2. Based on the numerical summaries reported in #3, which group (unrestricted or deprived) had the higher variability in improvement?
3. Calculate the observed difference in means for the improvements of the two groups. Record this value.

$\overbar{x}$unrestricted  - $\overbar{x}$deprived =

1. Before you conduct an inferential analysis, does this difference in sample averages strike you as a meaningful difference? Explain your answer.
2. What are two possible explanations for why we observed the two groups to have different sample means for improvement in performance?

Once again the key question is how often random assignment alone would produce a difference in the groups at least as extreme as the difference observed in this study, if there really were no effect of sleep condition on improvement score. We can use *simulation* to investigate how often such an extreme difference would occur by chance (random assignment) alone (if the hypothesis of no difference / no effect / no association were true).

A natural statistic for measuring how different the observed group means are from each other is the difference in the average improvement scores between the two groups.

Start by using index cards to perform a tactile simulation of randomly assigning the 21 subjects between the two groups, *assuming* that sleep condition has no impact on improvement. Because we are investigating what might occur when improvement score is not associated with sleep condition, we will assume that the 21 subjects would have had exactly the same improvement scores as they did, *regardless* of which sleep condition group (unrestricted or deprived) the subject had been assigned.

1. How many index cards do you need to conduct this simulation?
2. What will you write on each index card?

To conduct *one repetition* of this simulation:

* Shuffle the stack of 21 cards well, and then randomly distribute cards into two stacks: one stack with 10 cards (the unrestricted group) and one with 11 (the sleep deprived group).
* Calculate and report the sample averages for each re-randomized group:

Re-randomized unrestricted group’s average:

Re-randomized deprived group’s average:

* Calculate the difference in group means, subtracting unrestricted average minus sleep deprived average. Report this value.
* Combine this result with your classmates’ to create a dotplot that shows the distribution of several possible values of difference in sample averages that could have happened due to pure chance, if sleep condition has no impact on improvement. Sketch the dotplot here.



1. At about what value is the dotplot centered? Explain why this makes sense. (*Hint*: What are we assuming to be true when we conduct the simulation?)
2. Where is the observed difference in averages from the original study (as reported in #6) on the dotplot? Did this value happen often, somewhat rarely, or very rarely? How are you deciding?
3. You would now need to conduct many, many more repetitions to determine what is typical and what is not for the difference in group averages, assuming that sleep condition has no impact on improvement score. Rather than continue to shuffle cards for a very long time and calculating difference of group means by hand, you can use an applet to carry out the simulation. Go the **Randomization Test for Quantitative Response** applet (<http://www.rossmanchance.com/applets/randomization20/Randomization.html> ) and press **Re-randomize**.
4. Record the simulated difference in sample averages for the re-randomized groups, as given in the applet output. Is this difference more extreme than the observed difference from the study (as reported in #6)? How are you deciding?
5. Click on **Re-randomize** again, and record the simulated difference in sample averages for the re-randomized groups. Did it change from #10a?
6. Click on **Re-randomize** again, and record the simulated difference in sample averages for the re-randomized groups. Did it change from #10a and #10b?
7. Now to see many more possible values of the difference in sample averages, assuming sleep condition has no impact on improvement, do the following on the **Randomization Test for Quantitative Response** applet:
* Uncheck **Animate**.
* Change **Number of repetitions** to 997.
* Press **Re-randomize**, to produce a total of 1000 shuffles and re-randomizations.
1. Consider the dotplot (at the bottom of the screen) of the 1000 possible values of difference in sample averages, assuming that sleep condition has no effect on improvement.
	1. What does one dot on the­­­ dotplot represent? (*Hint*: Think about what you would have to do to put another dot on the graph.)
	2. Describe the overall shape of this dotplot.
	3. Where does the observed difference in sample averages (as reported in #6) fall in this dotplot: near the middle or out in a tail? Are there a lot of dots that are even more extreme than the observed difference, assuming sleep condition has no impact on improvement? How are you deciding?
2. Based on the simulated distribution, evaluate the strength of evidence provided by the experimental data against the hypothesis that sleep condition has no effect on improvement score: not much evidence, moderate evidence, strong evidence, or very strong evidence?
3. Summarize your conclusion with regard to strength of evidence in the context of this study.