Exam 1

Data Science for Studying Language & the Mind

Instructions

The exam is worth **XXX points**. You have **1 hours and 30 minutes** to complete the exam.

- The exam is closed book/note/computer/phone except for the provided reference sheets
- If you need to use the restroom, leave your exam and phone with the TAs
- If you finish early, you may turn in your exam and leave early

(5 points) Preliminary questions

Please complete these questions *before* the exam begins.

(a) **(1 point)** What is your full name?

(b) **(1 point)** What is your penn ID number?

(c) **(1 point)** What is your lab section TA's name?

(d) **(1 point)** Who is sitting to your left?

(e) **(1 point)** Who is sitting to your right?

1. (6 points) R basics: general

(a) **(2 points)** Which of the following are expressions? Choose all that apply.

- ☐ `x <- 5`
- ☐ `mean(data)`
- ☐ `4 + 2`
- ☐ `"Hello, world!"`
- ☐ `y <- 4 + mean(2)`

(b) **(2 points)** Which of the following occur in the code block below? Choose all that apply

```
x <- 5 + 3
```

- ☐ a message
- ☐ a comment
- ☐ a function
- ☐ the assignment operator

(c) **(2 points)** What additional step do we need to take to start a new R notebook in Google Colab with `File > New notebook`? Choose one.

- ☐ `File > Download > Download .ipynb`
- ☐ `File > Download > Download .py`
- ☐ `Runtime > Change runtime type` and select R
- ☐ No further action needed. R is the default notebook for Google Colab

2. (16 points) R basics: vectors, operations, subsetting

(a) **(3 points)** Use the `seq()` function to write an expression that would return the vector `100 200 300 400 500` and store it as `my_vector`

(b) **(2 points)** Suppose you run the following code. What will `typeof(x)` return and why? Choose one.

```
x <- c(30, 40, 50, "sixty", 70, 80)
```

- ☐ `double` due to implicit coercion
- ☐ `double` due to explicit coercion
- ☐ `character` due to implicit coercion
- ☐ `character` due to explicit coercion
- ☐ `Error: vectors must be atomic`

(c) **(2 points)** What will the following code block return? Choose one.

```
x <- 50:60
typeof(x)
```

- ☐ `integer`
- ☐ `double`
- ☐ `matrix`
- ☐ `vector`

(d) **(3 points)** Suppose you run the following code. What will be returned? Choose one.

```
c(1, 2, 3) * c(1, 2, 3)
```

- ☐ `2 4 6`
- ☐ `1 4 9`
- ☐ `1 2 3 2 4 6 3 6 9`
- ☐ `2 3 4 3 4 5 3 5 6`
- ☐ Error: non-numeric argument to binary operator‘

(e) **(2 points)** Suppose you run the following code. What will `x[c(2,4)]` return? Write your answer in the box below and *show your work.*

```
x <- seq(1, 10, by = 2)
```


(f) **(2 points)** In R, how are complex objects like matricies or arrays built? Choose one.

- ☐ lists with named elements
- ☐ vectors with attributes
- ☐ arrays of numbers
- ☐ nested loops
- ☐ none of the above

(g) **(2 points)** Suppose we run the following code. What will `is.na(x)` return? Choose one.

```
x <- c("apple", NA, "na", "orange")
```

- ☐ `TRUE`
- ☐ `FALSE`
- ☐ `FALSE TRUE FALSE FALSE`
- ☐ `FALSE TRUE TRUE FALSE`
- ☐ `2`

4. (11 points) Data visualization: basics

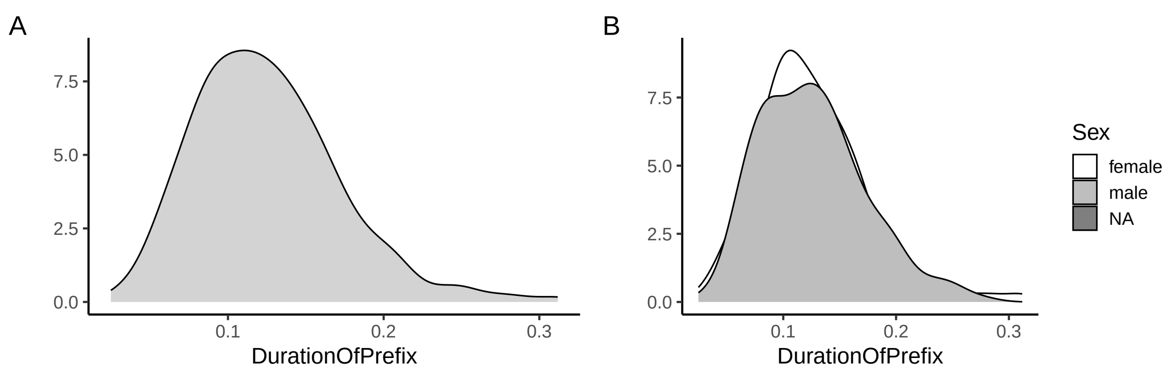
Suppose you are analyzing the `durationsGe` dataset, which includes the duration of the prefix ge- in Dutch by various speakers from the Spoken Dutch Corpus, glimpsed here.

```
Rows: 428
Columns: 8
$ Word                <fct> geprikt, gepresteerd, gevolgd, geprikkeld, gestaak~
$ Frequency           <int> 13, 25, 309, 16, 40, 42, 1301, 10, 73, 19, 39, 6, ~
$ Speaker             <fct> N01159, N01077, N01032, N01128, N01204, N01151, N0~
$ Sex                 <fct> male, male, female, female, female, female, male, ~
$ YearOfBirth         <int> 1944, 1980, 1939, 1979, 1963, 1956, 1979, 1944, 19~
$ DurationOfPrefix    <dbl> 0.238703, 0.082057, 0.120832, 0.106897, 0.133441, ~
$ SpeechRate          <dbl> 3.144654, 6.882591, 6.870229, 7.217848, 5.866667, ~
$ NumberSegmentsOnset <int> 2, 2, 1, 2, 2, 1, 2, 2, 1, 3, 1, 2, 1, 2, 3, 1, 2,~
```

Then, you use the following code to generate the plots below.

```r
# Code 1
ggplot(durationsGe, aes(x = DurationOfPrefix, fill = Sex)) +
    geom_density(fill = "lightgray") +
    theme_classic(base_size = 12) +
    labs(y = "") +
    scale_fill_manual(values = c("white", "gray", "black"))

# Code 2
ggplot(durationsGe, aes(x = DurationOfPrefix)) +
    geom_density(fill = "lightgray") +
    theme_classic(base_size = 12) +
    labs(y = "")
```



(a) **(3 points)** Which of plots A and B did Code 1 and 2 generate? Choose one.

- ☐ Code 1 generates plot A, code 2 generates plot B
- ☐ Code 2 generates plot A, code 1 generates plot B
- ☐ Code 1 and 2 both generate plot A
- ☐ Code 1 and 2 both generate plot B
- ☐ Code 1 and 2 generate neither plot A nor plot B

(b) **(2 points)** Which geoms could be depicted in plots A and B above? Choose all that apply.

- ☐ `geom_histogram()`
- ☐ `geom_smooth()`
- ☐ `geom_line()`
- ☐ `geom_density()`
- ☐ `geom_bar()`

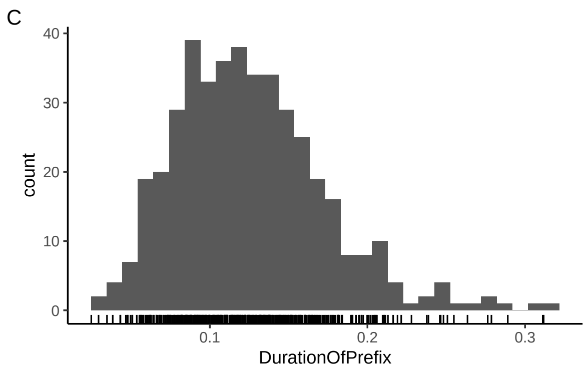
(c) **(3 points)** Consider the following code blocks 3 and 4. Would they generate identical figures? Explain why or why not in the box below.

```
# Code 3
ggplot(
    data=durationsGe,
    mapping = aes(y = DurationOfPrefix, x = Sex)) +
        geom_bar(stat = "identity")

# Code 4
  ggplot(
    aes(y = DurationOfPrefix, x = Sex), durationsGe) +
    geom_bar(stat = "identity")
```

(d) **(3 points)** The code below makes use of a new geom, `geom_rug()`, to generate plot C, in which each individual data point is plotted along the x-axis like a "rug".

```
ggplot(durationsGe, aes(x = DurationOfPrefix)) +
    geom_rug() +
    geom_histogram() +
    theme_classic(base_size = 12)
```

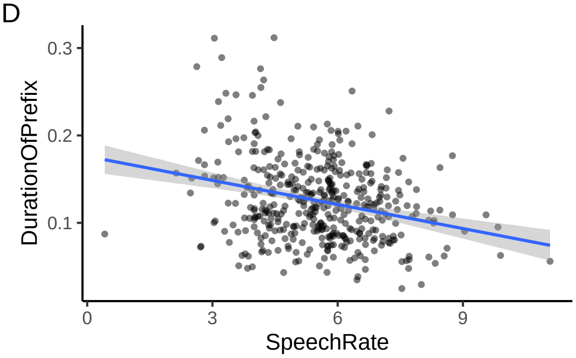


In the box below, rewrite the code such the color of the rug is mapped to the `Sex` variable and the bars of the histogram are filled in with the color "lightblue".

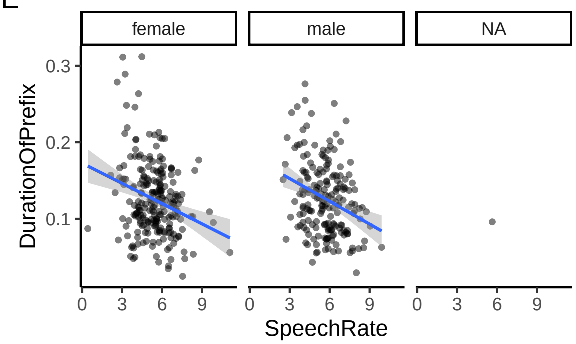
5. (9 points) Data visualization: layers

Suppose you now want to visualize the `SpeechRate` variable in the `durationsGe` dataset, which codes a speakers speech rate in number of sylalbuse per second.

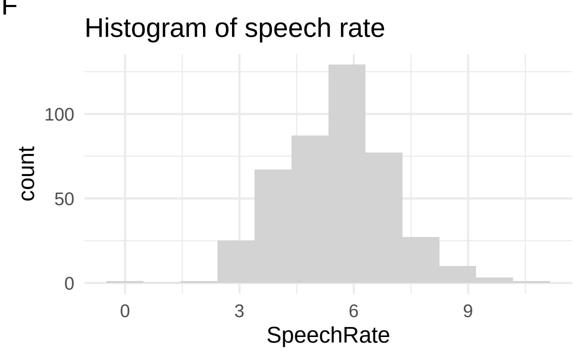
D



E



F



(a) **(2 points)** True of false, adding the argument `position = "jitter"` to `geom_point()` would add a small amount of random noise around each point in plot D?

- ☐ True
- ☐ False

(b) **(2 points)** Which of the following would change plot D to plot E? Choose one.

- ☐ add layer `facet_wrap(~ Sex)`
- ☐ add layer `facet_grid(. ~ Sex)`
- ☐ add layer `facet_grid(Sex ~ .)`
- ☐ add layer `facet_grid(Word ~ Sex)`
- ☐ add layer `facet_by_sex()`

(c) **(2 points)** Which of the following arguments to `geom_histogram()` could be present in the code that returned plot F? Choose all that apply.

- ☐ `bins=12`
- ☐ `bins=1`
- ☐ `binwidth=1`
- ☐ `binwidth=12`

(d) **(3 points)** Which of the following layers must be present in the code that returned plot F? Choose all that apply.

- ☐ `theme_minimal(base_size = 15)`
- ☐ `theme_minimal(font_size = 15)`
- ☐ `labs(title = "Histogram of speech rate")`
- ☐ `labs(caption = "Histogram of speech rate")`
- ☐ `facet_grid(.~ count)`

3. (10 points) Data importing

(a) **(2 points)** Which `tidyverse` package do we use to import data? Choose one.

- ☐ `dplyr`
- ☐ `readr`
- ☐ `importr`
- ☐ `ggplot2`
- ☐ `googlesheets2`
- ☐ `purrr`

(b) **(2 points)** True or false, the following code blocks return the same tibble.

```
tibble(
    x = 1:2,
    y = 3:4,
    z = 5:6
)

tribble(
    ~x, ~y, ~z,
    ~1, 3, 5,
    ~2, 4, 6
)
```

- ☐ True
- ☐ False

(c) **(3 points)** Suppose you import "junesales.csv", shown below, with the following code. What would `data$Sale` return? Choose one.

```
Year, Month, Day, Sale
2023, June, 1, 0
2023, June, 2, 1
2023, June, 3, 0
2023, June, 4, 1
```

```
data <- read_csv("junesales.csv",
    col_types = list(Sale = col_logical())
)
```

- ☐ A `double` vector with values `0 1 0 1`
- ☐ A `logical` vector with values `FALSE TRUE FALSE TRUE`
- ☐ A double vector with values `NA NA NA NA`
- ☐ Error: Cannot coerce col to logical

(d) **(3 points)** Suppose you import a dataset with but when you `print(data)` you notice that the `age` column was identified as `character` when you were expecting `double`. Given the resulting tibble, which of the following arguments could you include in blank in the code below to solve this problem? Choose one.

```
# A tibble: 4 x 3
  age   graduated   gpa
  <chr> <lgl>     <dbl>
1 18    FALSE      NA
2 na    FALSE       3.8
3 25    TRUE        2.9
4 21    TRUE        3.1
```

```
data <- read_csv("data.csv", ________)
```

- ☐ `.drop = NA`
- ☐ `skip = 2`
- ☐ `guess_max = Inf`
- ☐ `na = c("na")`
- ☐ `col_names = FALSE`

6. (15 points) Data wrangling

Now that you've done some initial visualizations of the `durationsGe` data, you realize you need to do some data wrangling. Here's a glimpse at the data again to refresh your memory.

```
Rows: 428
Columns: 8
$ Word                <fct> geprikt, gepresteerd, gevolgd, geprikkeld, gestaak~
$ Frequency           <int> 13, 25, 309, 16, 40, 42, 1301, 10, 73, 19, 39, 6, ~
$ Speaker             <fct> N01159, N01077, N01032, N01128, N01204, N01151, N0~
$ Sex                 <fct> male, male, female, female, female, female, male, ~
$ YearOfBirth         <int> 1944, 1980, 1939, 1979, 1963, 1956, 1979, 1944, 19~
$ DurationOfPrefix    <dbl> 0.238703, 0.082057, 0.120832, 0.106897, 0.133441, ~
$ SpeechRate          <dbl> 3.144654, 6.882591, 6.870229, 7.217848, 5.866667, ~
$ NumberSegmentsOnset <int> 2, 2, 1, 2, 2, 1, 2, 2, 1, 3, 1, 2, 1, 2, 3, 1, 2,~
```

(a) **(3 points)** The `Sex` variable in the `durationsGe` dataset has the following distinct values: `"male" "female" NA`. How many rows would be in the object returned by the following code block? Choose one.

```
durationsGe %>%
    filter(Sex %in% c("female")) %>%
    summarise(minBirthYear=min(YearOfBirth, na.rm=TRUE), .by=c(Sex))
```

- ☐ 1
- ☐ 3
- ☐ 428
- ☐ However many female speakers there were in the dataset
- ☐ However many birth years there were in the dataset

(b) **(6 points)** Fill in the blanks in the partially completed code below such that it returns the following tibble, including the `mean` and `sd` of the `DurationOfPrefix` variable.

```
durationsGe %>% group_by(__a__) %>% summarise(____b_____, _____c_______)
```

```
# A tibble: 3 x 3
  Sex      mean      sd
  <fct>   <dbl>   <dbl>
1 female 0.125   0.0480
2 male   0.126   0.0468
3 <NA>   0.0960 NA
```

(i) **(2 points)** Fill in blank a.

(ii) **(2 points)** Fill in blank b.

(i) **(2 points)** Fill in blank c.

(c) **(3 points)** Consider the following code options. Would they return identical tibbles? Explain why or why not in the box below.

```
# option 1
durationsGe %>%
    select(Frequency) %>%
    filter(Frequency > 40) %>%
    distinct()

# option 2
just_freq <- select(durationsGe, Frequency)
freq_under_40 <- filter(just_freq, Frequency > 40)
distinct(freq_under_40)
```

(d) **(3 points)** Consider the following code options. Would they return identical tibbles? Explain why or why not in the box below.

```
# option 1
durationsGe %>%
    select(Freq=Frequency, Speaker:DurationOfPrefix) %>%
    mutate(AgeInYears = 2023 - YearOfBirth, .before = Freq)

# option 2
durationsGe %>%
    select(Frequency:DurationOfPrefix) %>%
    rename(Freq = Frequency) %>%
    mutate(AgeInYears = 2023 - YearOfBirth, .before = 1)
```

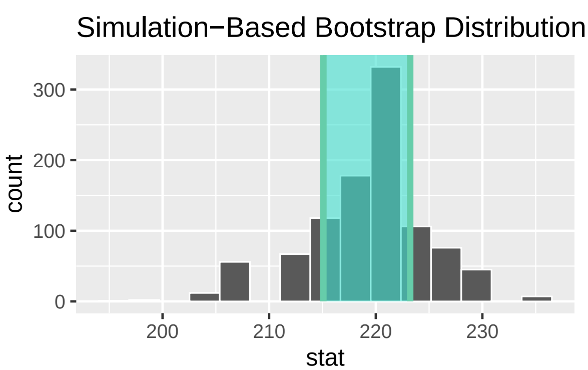
7. (10 points) Sampling distribution

The following data was simulated from Johnson & Newport (1989), a study investigating the English language proficiency of 46 native Korean or Chinese speakers who arrived in the US between the ages of 3 and 39. The researchers were interested in whether the participants' age of arrival to the United States played a role in their English language proficiency.

Suppose we returned a tibble with the number of data points (`n`), the `median`, and the IQR (`lower` and `upper`) grouped by `ageGroup`.

```
# A tibble: 5 x 5
  ageGroup     n median lower upper
  <chr>    <int>  <dbl> <dbl> <dbl>
1 0           23   268.  268.  270.
2 11-15        8   233.  228.  237.
3 17-39       23   220.  201.  233.
4 3-7          7   271.  269.  273.
5 8-10         8   263.  256.  266.
```

Then, suppose we used `infer` to generate the sampling distribution for the median proficiancy of the **17-39 year old age group**, visualize the distribution, and shade the confidence interval.



(a) **(2 points)** Which of the following best describes the statistics in the tibble?

- ☐ Both median and IQR are parametric
- ☐ Both median and IQR are nonparametric
- ☐ Meidan is parametric, but IQR is nonparametric
- ☐ Median is nonparametric, but IQR is parametric

(b) **(2 points)** The sampling distribution of the median looks approximately Gaussian. The probability densitiy function for the Gaussian distribution is given by which of the following equations?

- ☐ $\frac{\sum_{i=i}^{n} x_i}{n}$
- ☐ $\frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right)$
- ☐ $\frac{1}{max-min}$
- ☐ $\sqrt{\frac{\sum_{i=1}^{n}(x_i-\overline{x})^2}{n-1}}$

(c) **(3 points)** Fill in the blanks in the sentence below to describe what happens *on each repeat* in which we construct the sampling distribution via bootstrapping.

Draw _______________ data points ___________________ replacement, compute the _________________.

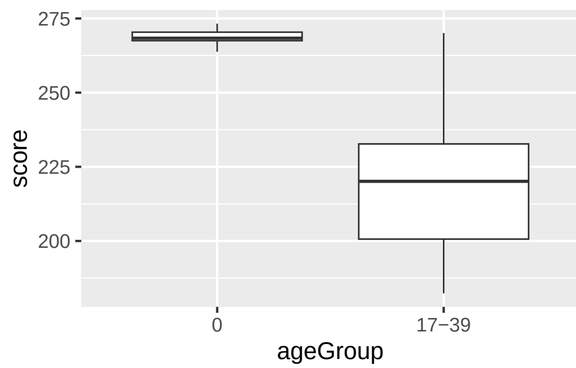
(d) **(3 points)** The shaded area of the figure shows a 68% confidence interval. If we were to increase the `level` of confidence to 95%, the confidence interval would become:

- ☐ Narrower
- ☐ Wider
- ☐ Unchanged
- ☐ There's insufficient information to determine this

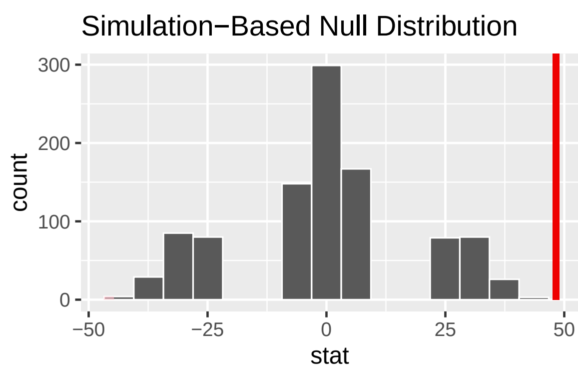
8. (11 points) Hypothesis testing

Suppose we want to know whether the participants who arrived as adults (17-39 age group) acheived native performance. We decide to address this question via the 3-step hypothesis testing framework in which we investigate the difference in **medians** between the native English speakers (0 age group) and the adults (17-39 age group).

We begin by visualizing the data.



Then, we use `infer` to generate the sampling distribution for the difference in **median proficiency** between the native English speakers (0 age group) and the adults (17-39 age group).



(a) **(2 points)** Which geom is best for our initial visualization of the data? Choose one.

- ☐ `geom_histogram()`
- ☐ `geom_violin()`
- ☐ `geom_boxplot()`
- ☐ `geom_density()`
- ☐ `geom_bar(stat = "identity")`

(b) **(2 points)** Step 1 of the 3-step hypothesis testing framework is to pose the null hypothesis. True or false, the null hypothesis here is that the observed difference in medians is due age group (age of arrival in the US).

☐ True
☐ False

(c) **(2 points)** Step 2 is to ask, if the null hypothesis is true, how likely is our observed pattern of results? We quantify this likelihood with:

☐ difference in medians
☐ correlation
☐ liklihood estimation
☐ p-value

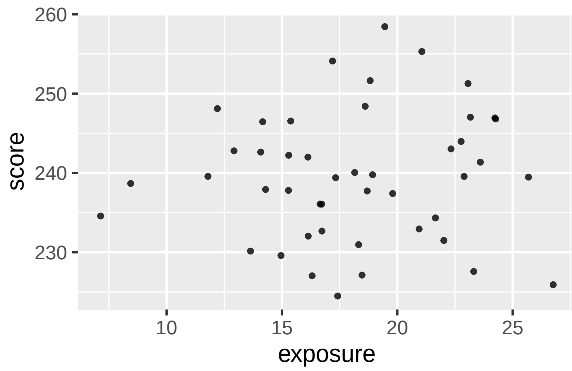
(d) **(2 points)** Step 3 is to decide whether to reject the null hypothesis. In the original paper, Johnson and Newport (1989) concluded that the two groups were significantly different from each other, suggesting that participants who arrived to the US after age 17 did not acheive native proficiency. This implies that they (choose one):

☐ Rejected the null hypothesis
☐ Failed to reject the null hypothesis
☐ Proved the research hypothesis to be true
☐ Proved the null hypothesis to be true
☐ All of the above

(e) **(3 points)** When we calculate the p-value from the simulated null distribution using the `get_p_value()` function, we get $\mathbf{p = 0}$. Is this a problem? Why or why not? Explain what a p-value of 0 means in this context.

9. (9 points) Correlation

Johnson and Newport (1989) also wanted to ask whether years of exposure to English predicted score on the English proficiency task. To address this, they computed the correlation between score and exposure.



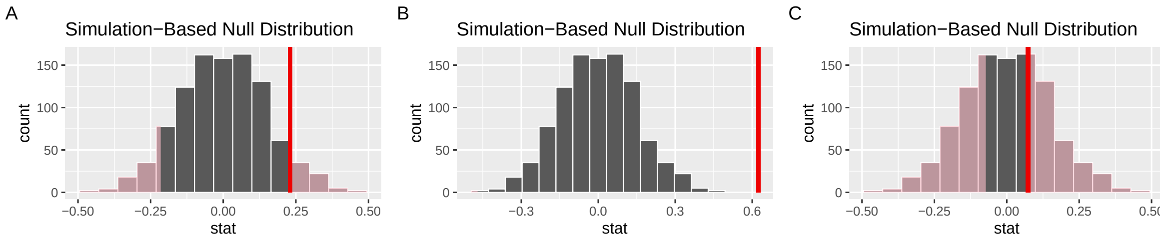
(a) **(2 points)** Given the scatterplot of these data, which of the following could be their observed correlation?

☐ -0.88
☐ 0.88
☐ 0.16
☐ 0.5

(b) **(2 points)** True or false, the correlations computed on these data were subject to sampling variability.

☐ True
☐ False

(c) **(3 points)** Johnson and Newport used hypothesis testing to determine whether the correlation they observed was significantly different from zero. We computed a p-value of `0.624` on the correlation we observed in our simulated data. Which figure could represent this p-value visualized on a null distribution generated nonparametrically from 1000 repetitions?



- ☐ A
- ☐ B
- ☐ C
- ☐ A or B, there is not sufficient information to differentiate
- ☐ A or C, there is not sufficient information to differentiate

(d) **(2 points)** What type of relationship does the correlation between years of exposure and score suggest?

- ☐ Linear
- ☐ Nonlinear
- ☐ Independence
- ☐ Permute