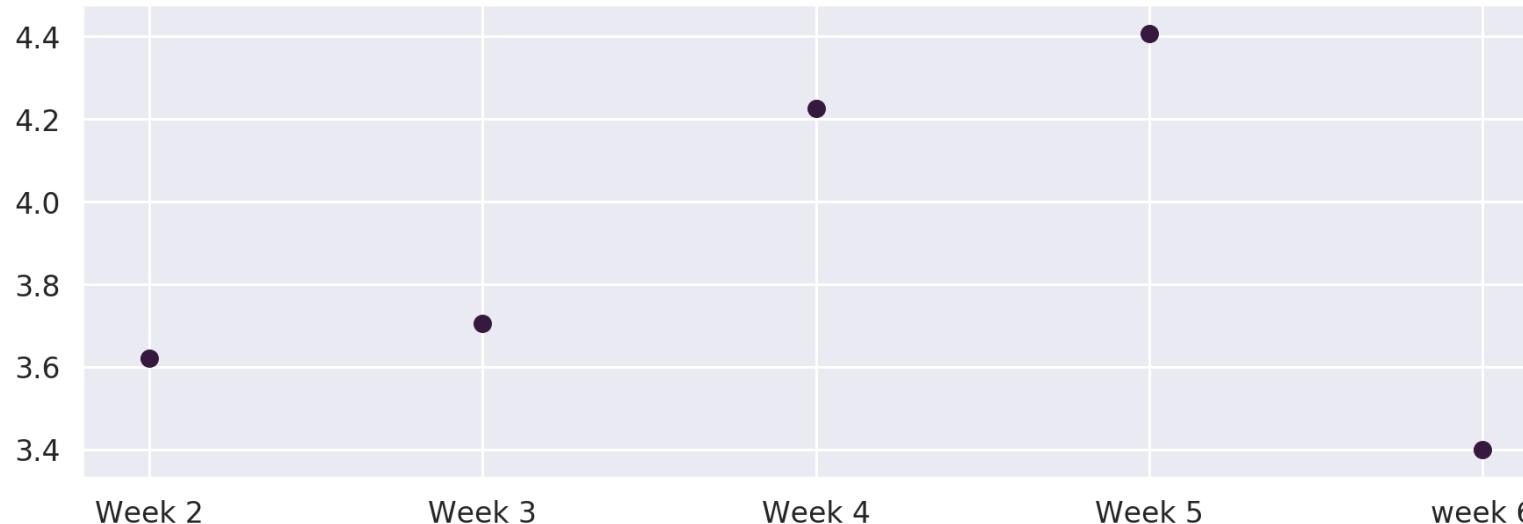


Black Holes Study

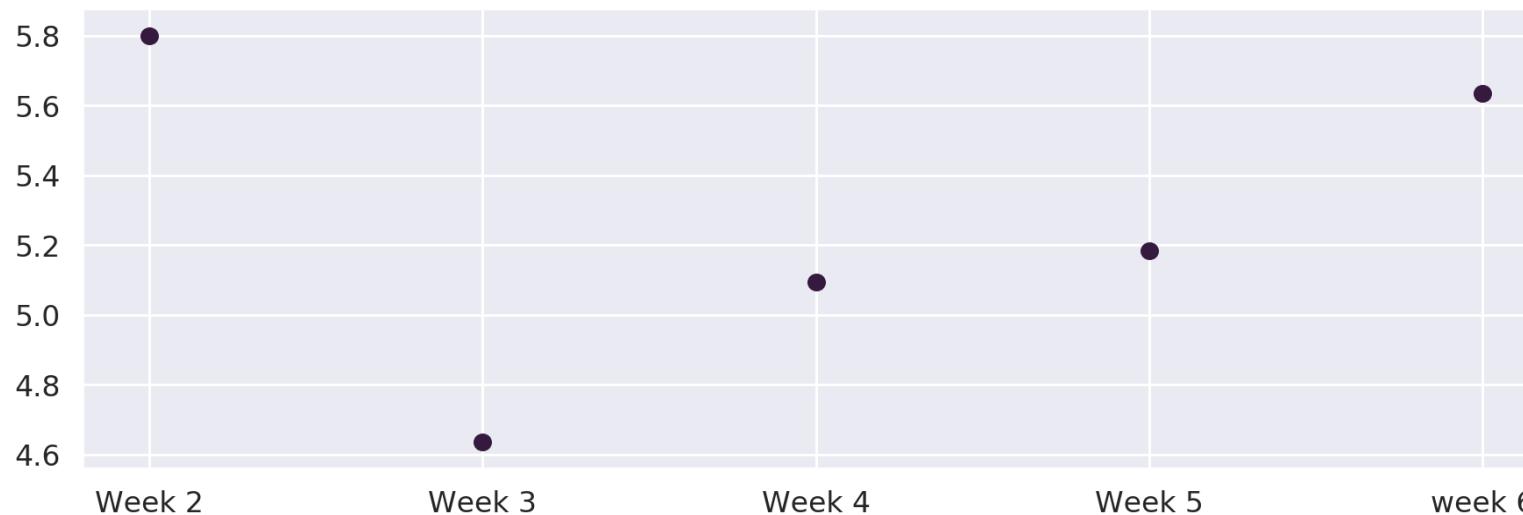
Participant Performance Across Data Collection - BH

Average Multiple Choice Gain Across Data Collection



$$F(4, 216) = 1.416, \quad p=0.230$$

Average Open Response Performance Across Data Collection



$$F(4, 216) = 1.093, \quad p= 0.361$$

VIVIDNESS OF VISUAL IMAGERY QUESTIONNAIRE (VVIQ)

For each item on this questionnaire, try to form a visual image, and consider your experience carefully. For any image that you do experience, rate how vivid it is using the five-point scale described below. If you do not have a visual image, rate vividness as '1'. Only use '5' for images that are truly as lively and vivid as real seeing. Please note that there are no right or wrong answers to the questions, and that it is not necessarily desirable to experience imagery or, if you do, to have more vivid imagery.

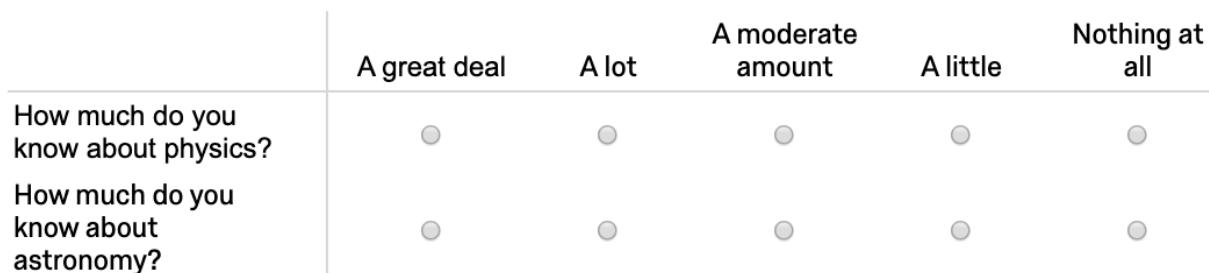
Perfectly clear and vivid as real seeing	5
Clear and reasonably vivid	4
Moderately clear and lively	3
Vague and dim	2
No image at all, you only "know" that you are thinking of the object	1

For items 1-4, think of some relative or friend whom you frequently see (but who is not with you at present) and consider carefully the picture that comes before your mind's eye.

1. The exact contour of face, head, shoulders and body _____
2. Characteristic poses of head, attitudes of body etc. _____
3. The precise carriage, length of step etc., in walking _____
4. The different colours worn in some familiar clothes _____

Visualise a rising sun. Consider carefully the picture that comes before your mind's eye.

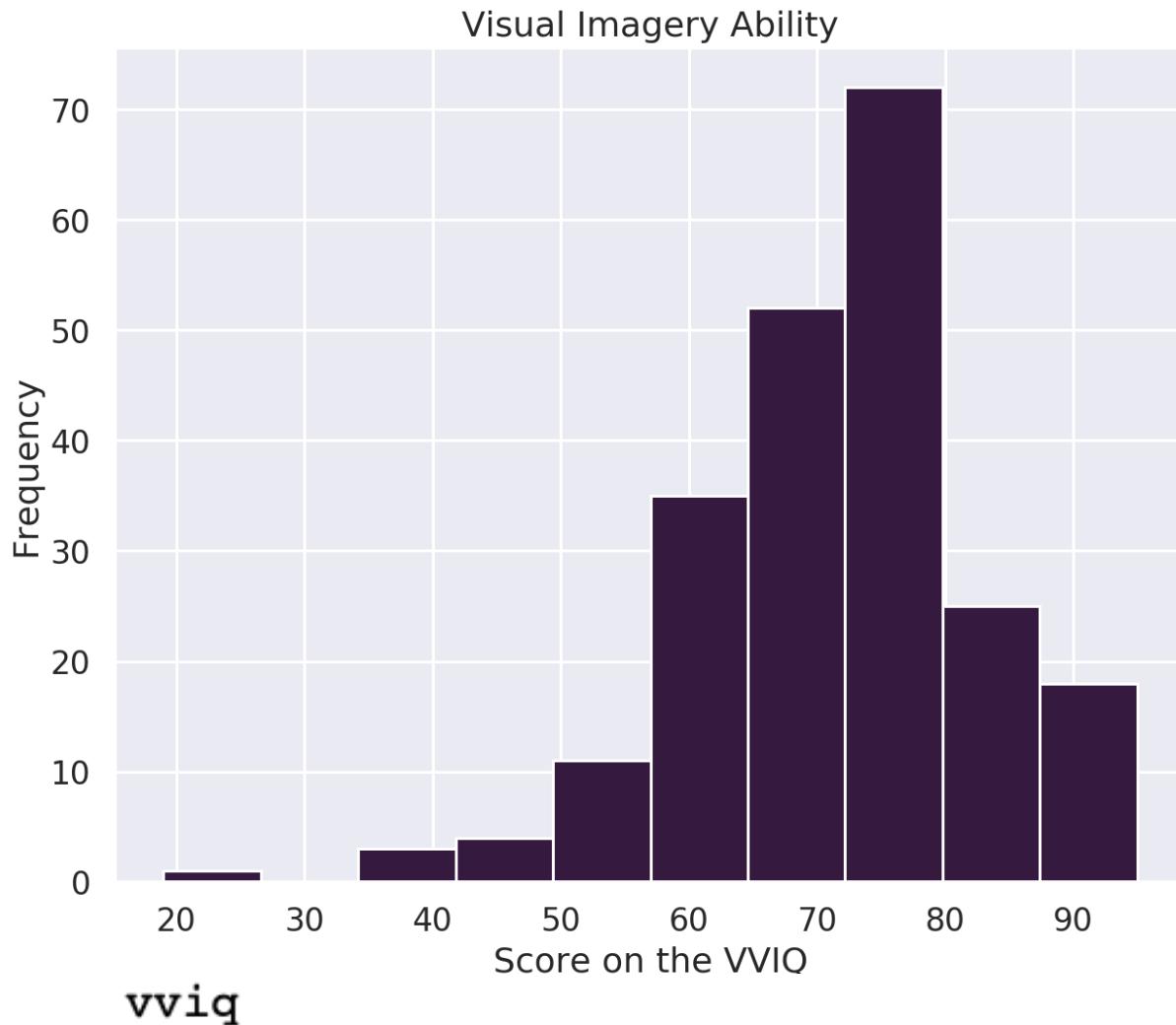
5. The sun rising above the horizon into a hazy sky _____
6. The sky clears and surrounds the sun with blueness _____
7. Clouds. A storm blows up with flashes of lightning _____
8. A rainbow appears _____



Measuring Individual Differences

- ❖ Imagery
- ❖ Prior knowledge

Visual Imagery Ability



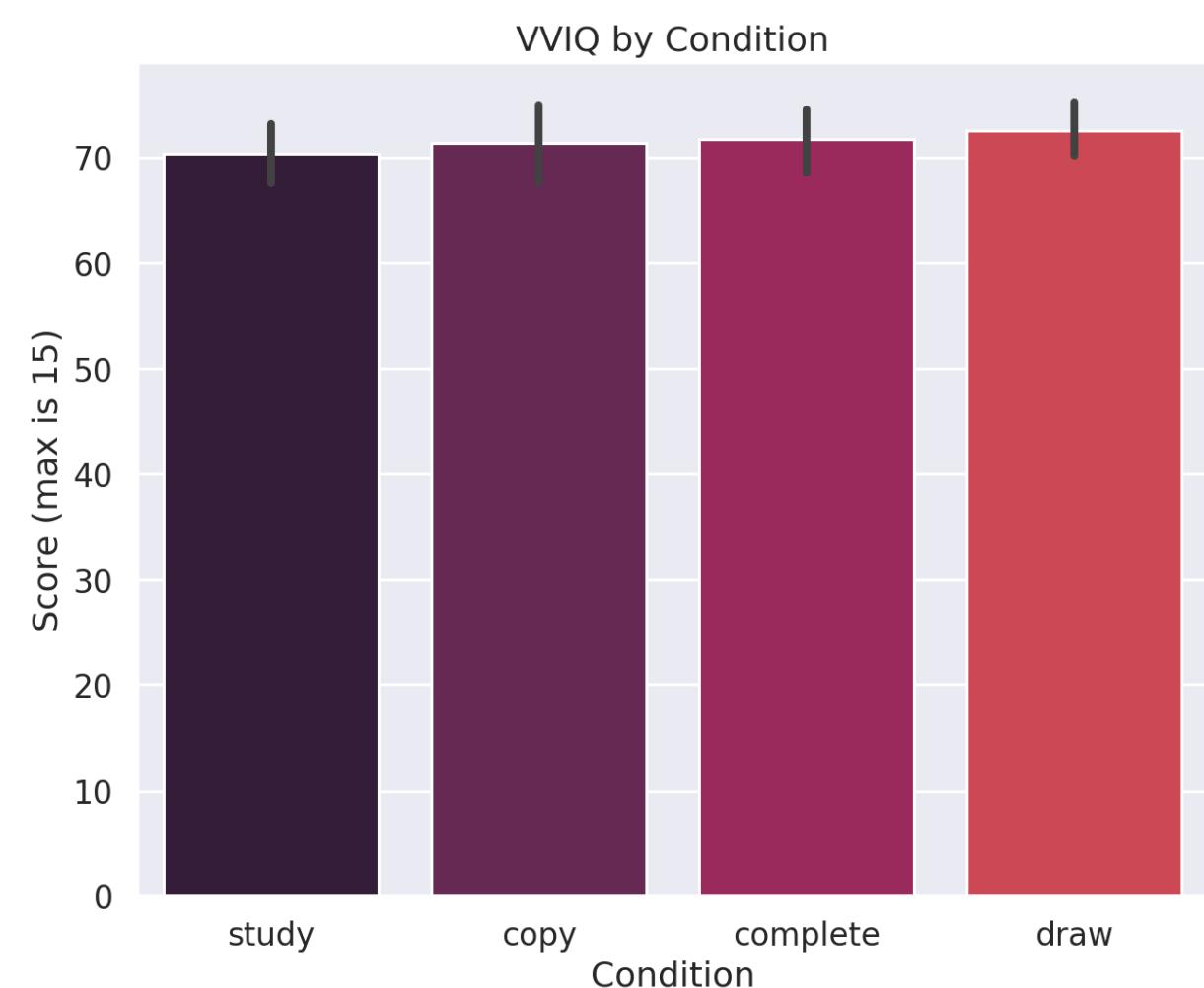
Mean: 71.471

Standard dev: 11.539

Min: 19.0

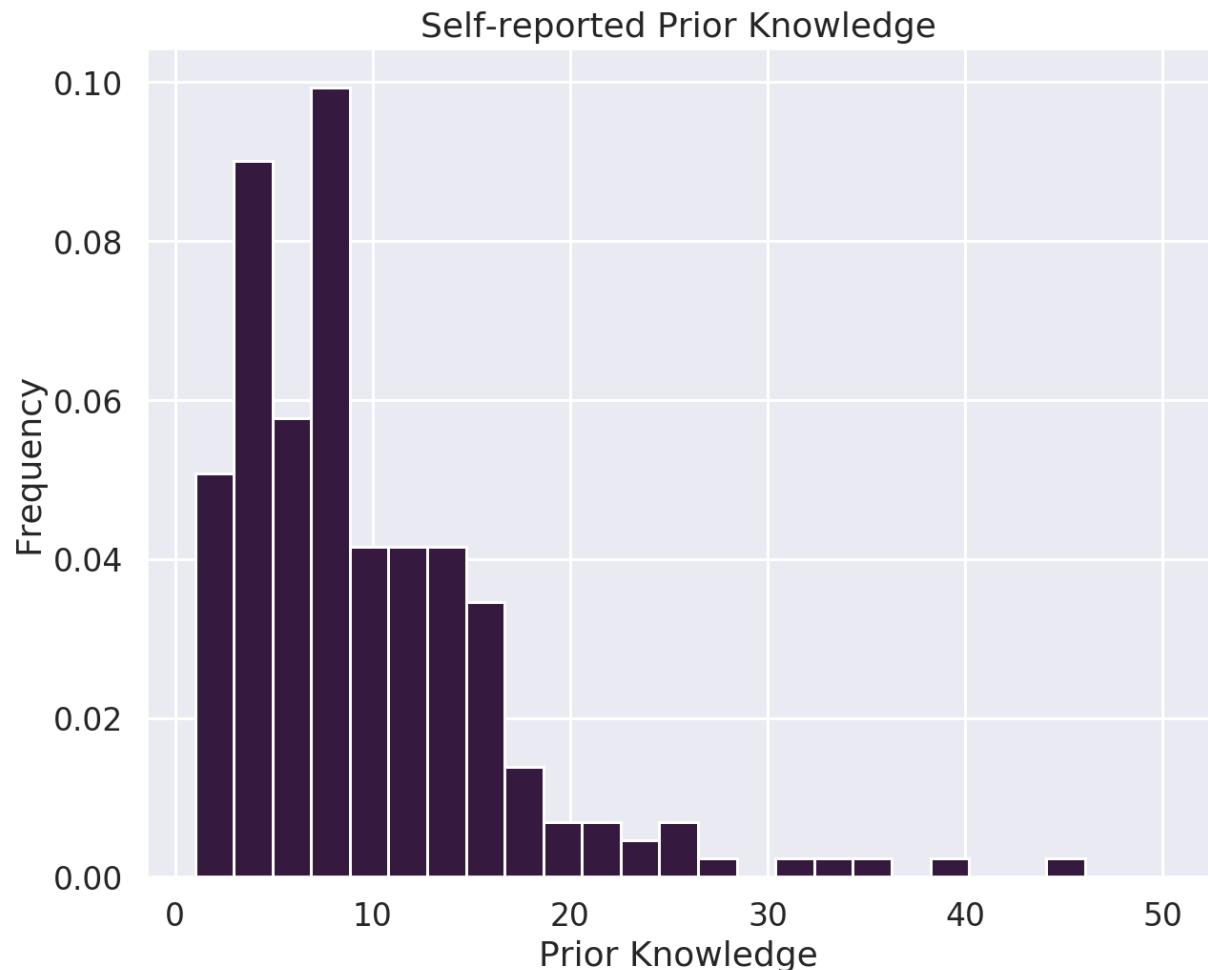
Median: 73.0

Max: 95.0



$F(3, 217) = 0.3263, p = 0.806$

Prior Knowledge



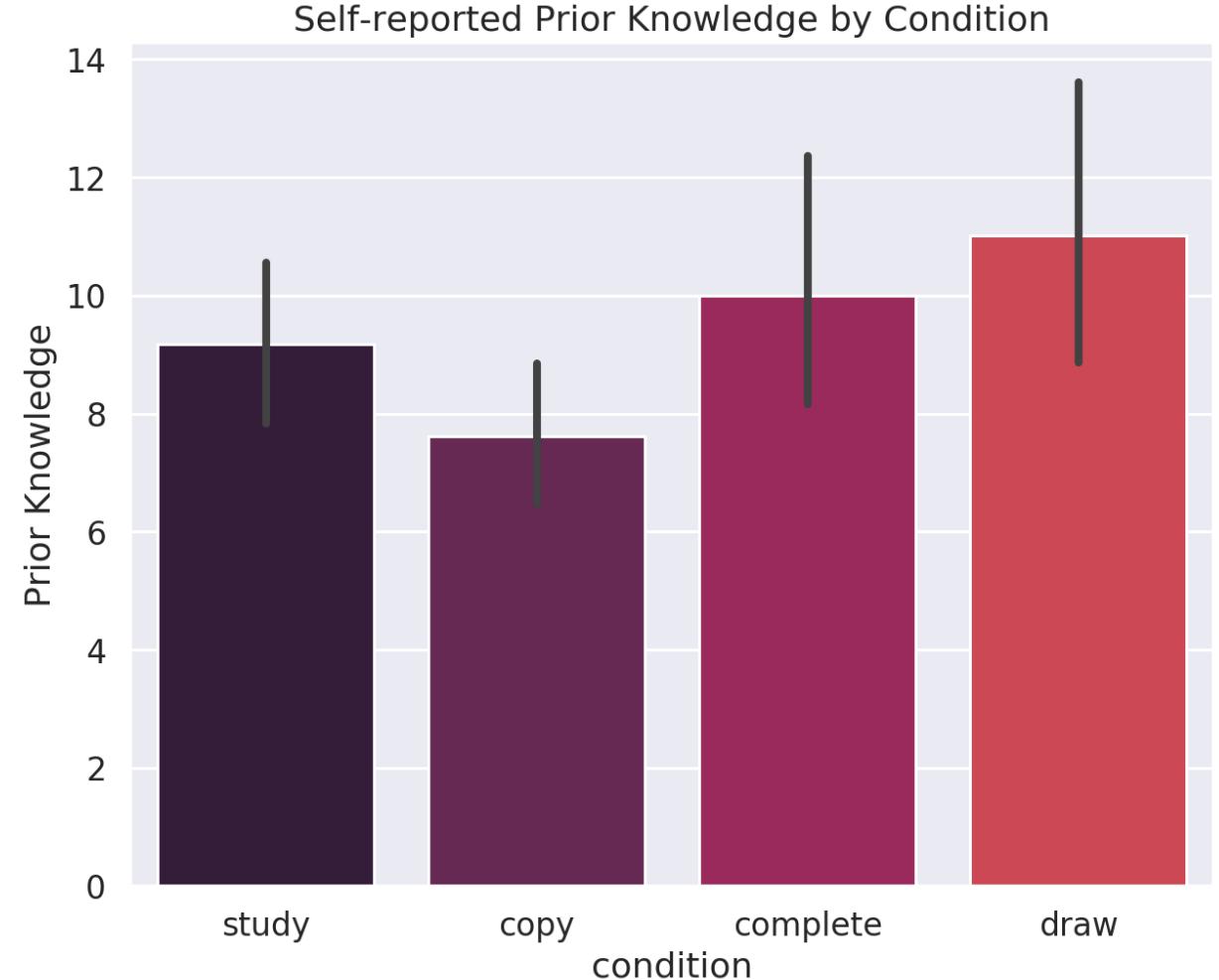
Self-reported Prior Knowledge

Mean: 9.407

Standard dev: 6.935

Min: 2 Median: 8.0

Max: 45



$$F(3, 217) = 2.391, \quad p = 0.0696$$

Multiple Choice Performance

Which of the following statements is true of spacetime?

- Near the event horizon space and time are not distinct entities.
- Time in the observable horizon has no dimension.
- Near the event horizon space and time are actively involved in defining it.
- How space and time are related is not actively involved in defining it.

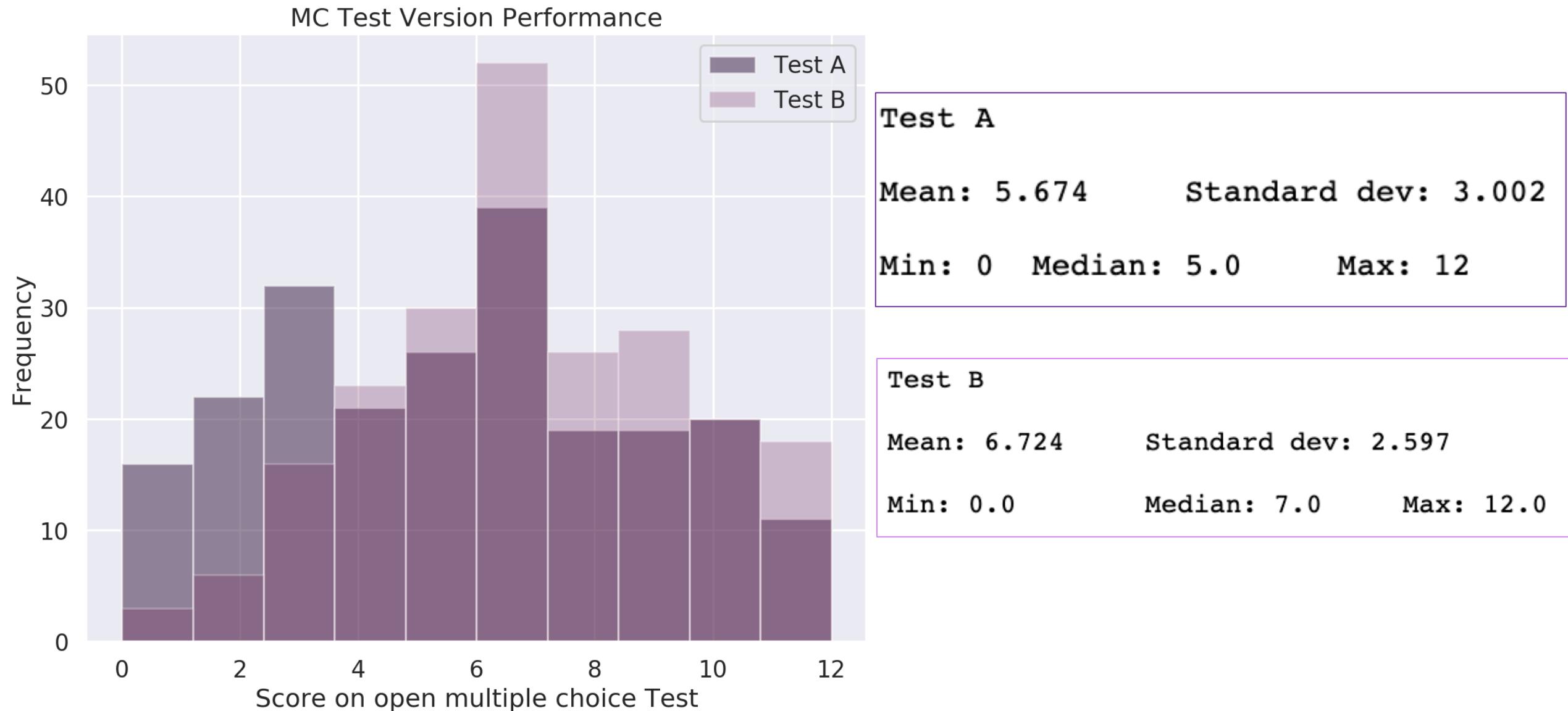
Which of the following is/are NOT true about a black hole?

- All stars collapse to become black holes upon their death.
- Matter that falls into a black hole reappears somewhere else in the universe.
- Black holes are comparable to vacuums as they suck material into their event horizon.
- The matter inside a black hole is not known because it lies beyond our observable universe.
- A and B
- A, B, and C

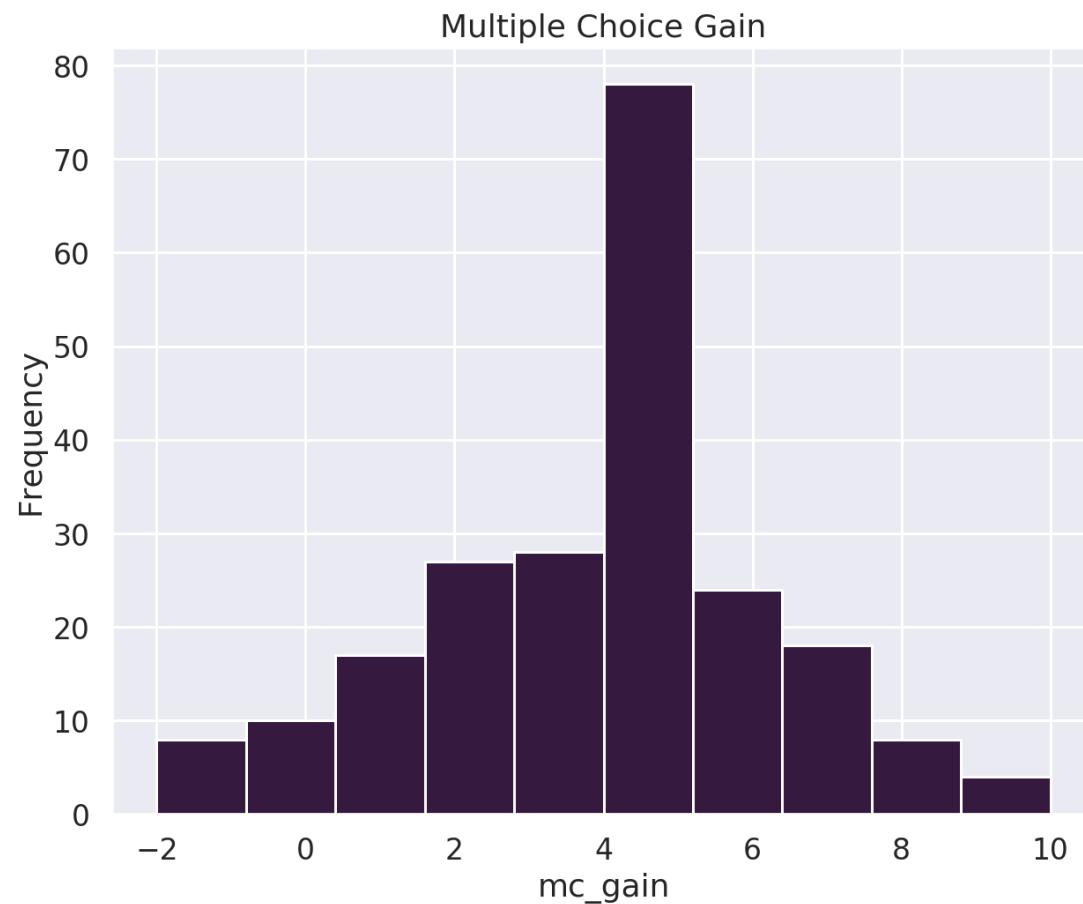
24 multiple choice questions

12 pre, 12 post-test

Test A vs Test B Performance



Multiple Choice Gain



Multiple choice gain

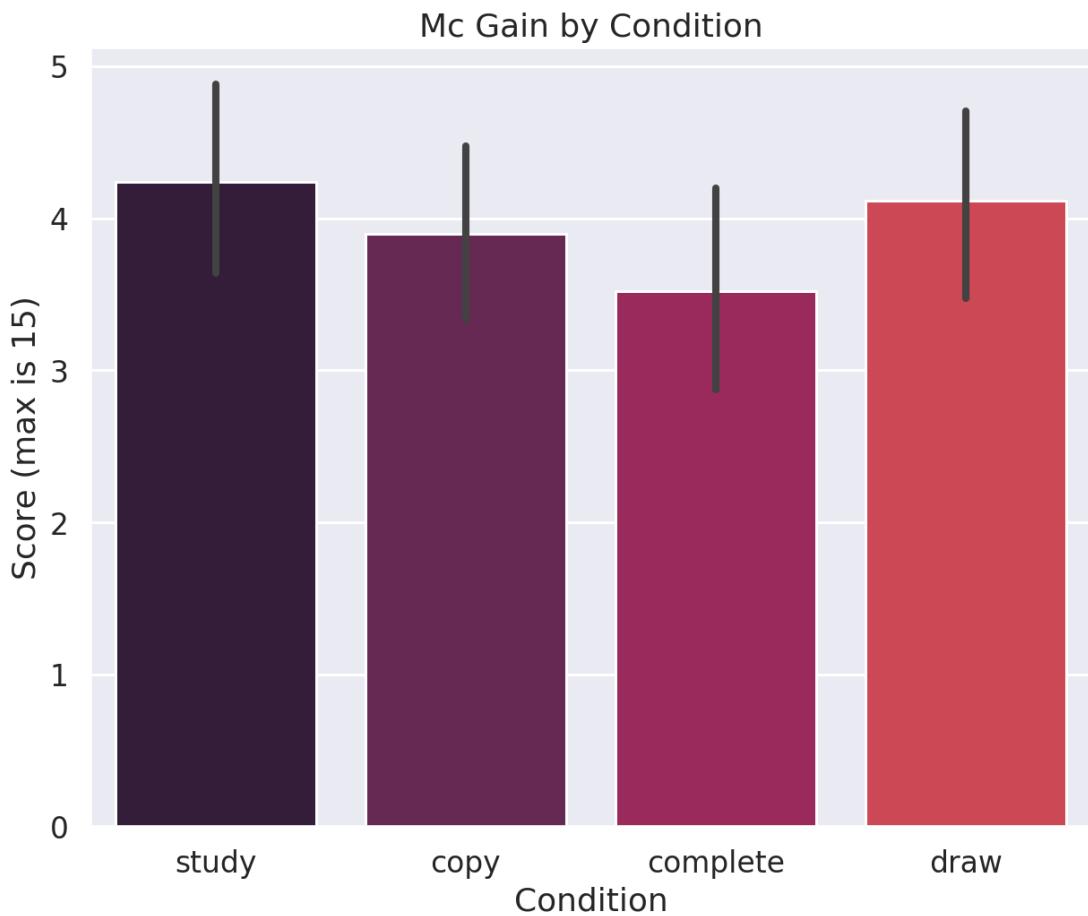
Mean: 3.928

Standard dev: 2.34

Min: -2.0

Median: 4.0

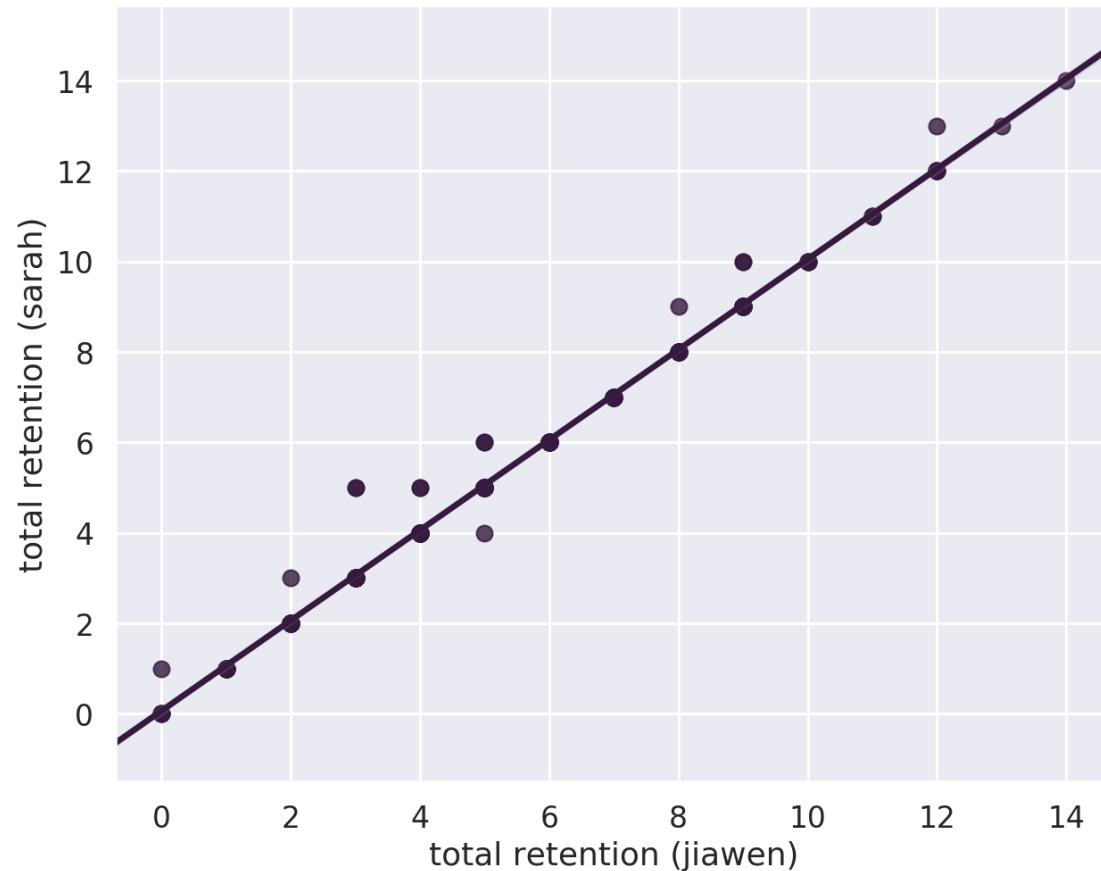
Max: 10.0



$F(3, 217) = 0.9316, p = 0.426$

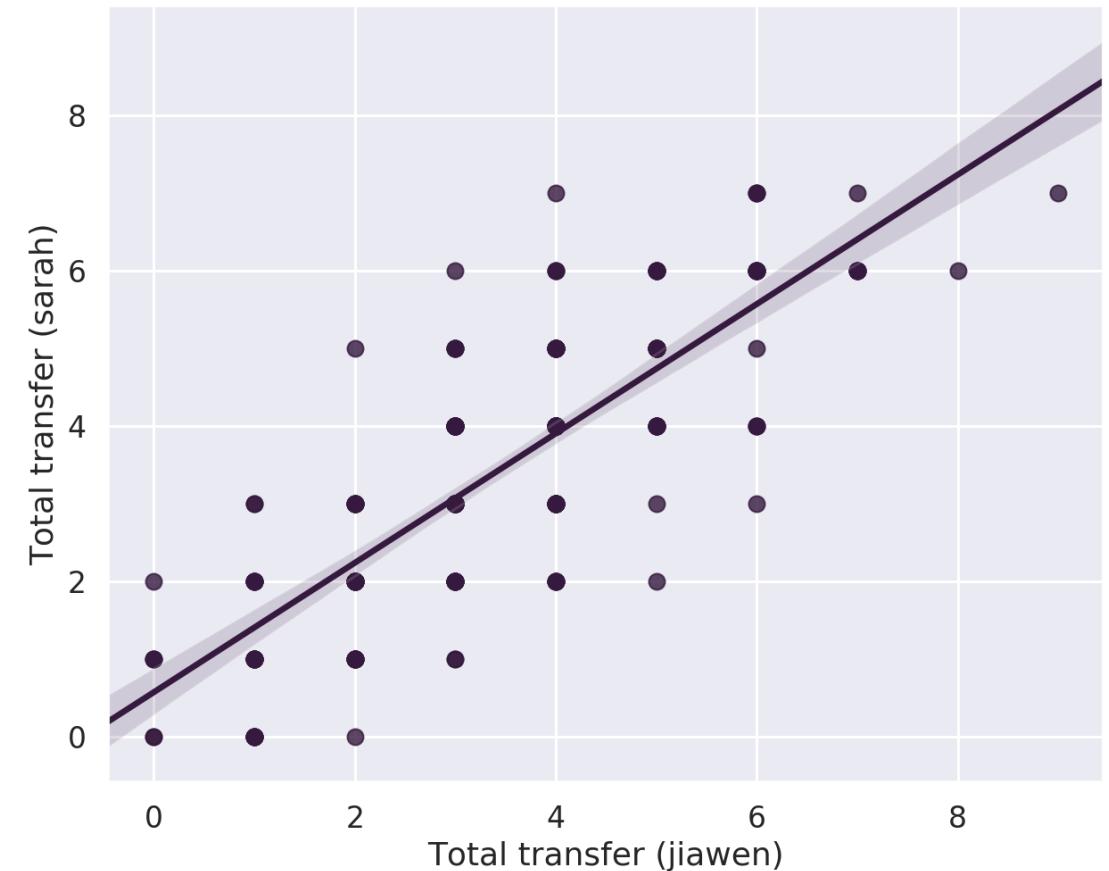
Coding

Retention



$r = 0.995, p < .0001$

Transfer



$r = 0.80, p < .0001$

Open Response Retention Performance

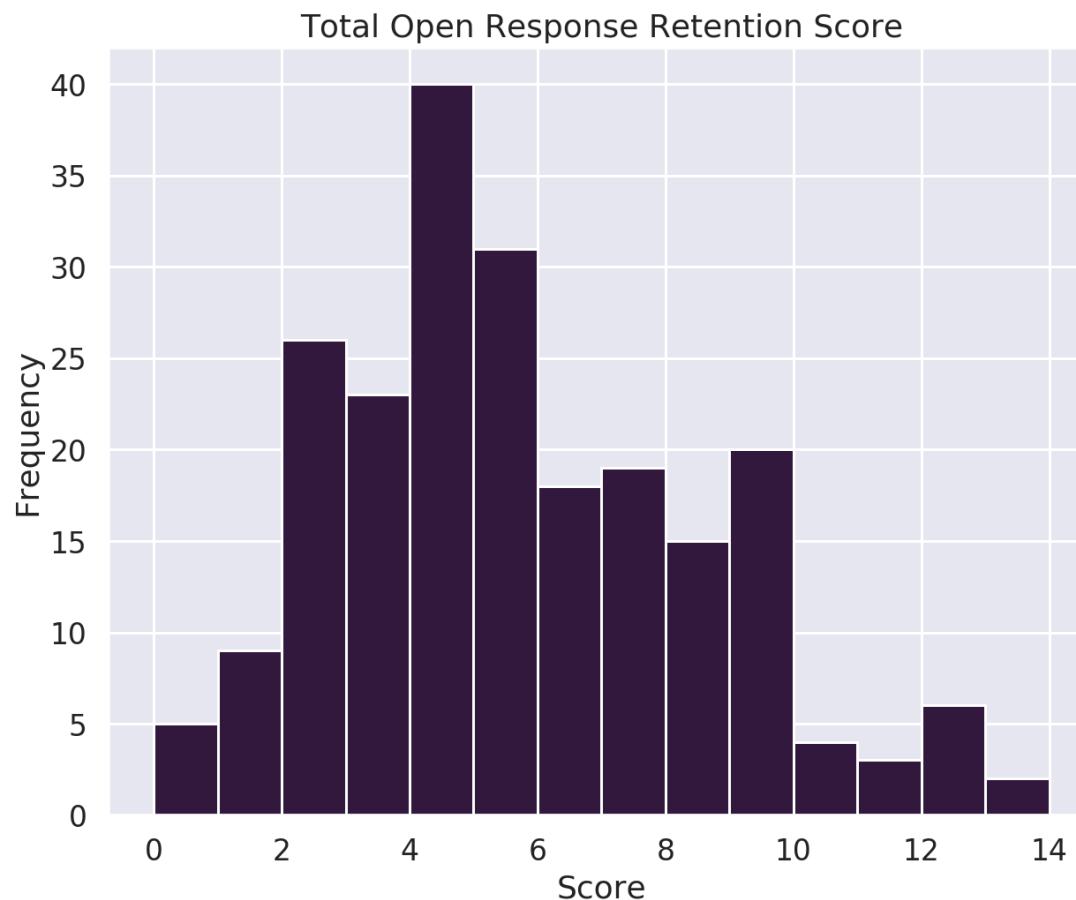
What is a black hole? Please explain in as much detail as you can.

How do black holes form? Please include everything you remember about this topic.

What is space and time like at the singularity of a black hole? What evidence do we have to support these theories?

The passage discussed some important properties of black holes. What properties do you remember? Please explain how the properties you do remember relate to black holes.

Retention



Retention

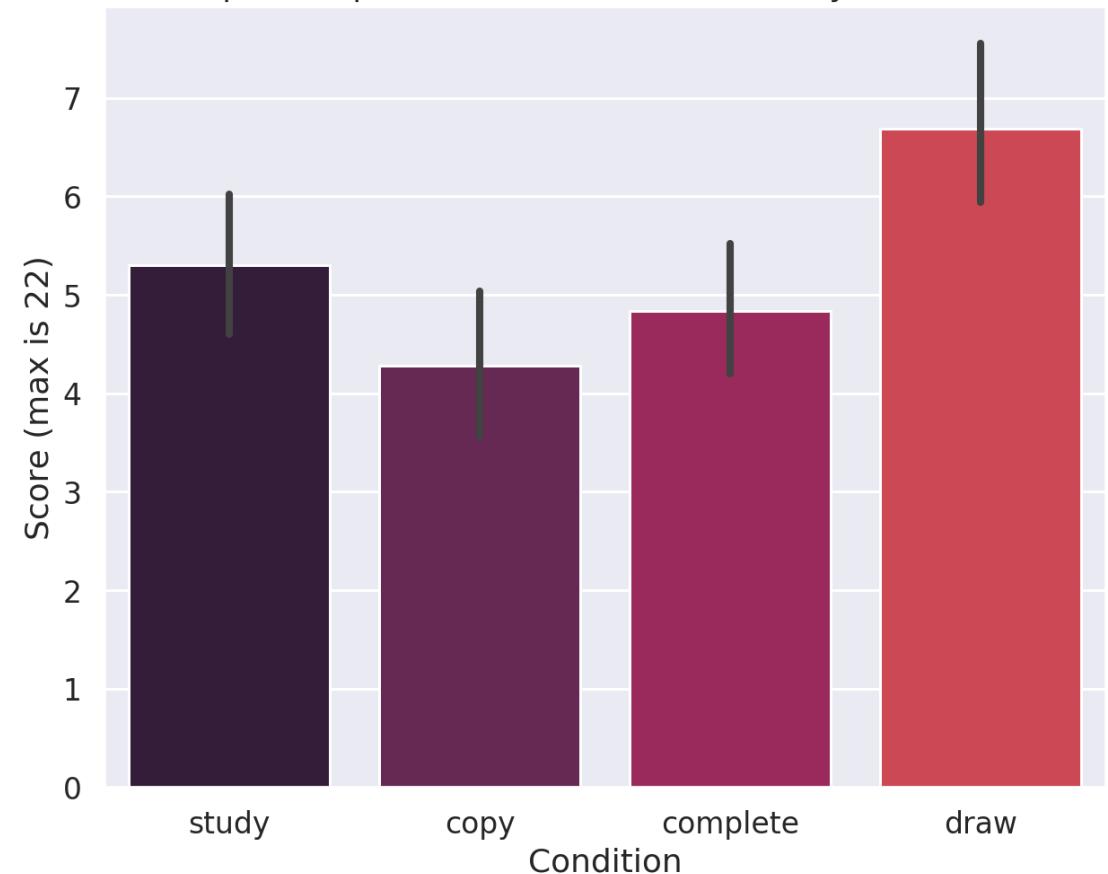
Mean: 5.24

standard dev: 2.875

Min: 0 Median: 5.0

Max: 14

Open Response Retention Test Score by Condition



$$F(3, 217) = 7.379, p = 0.0000991$$

Open Response - Transfer

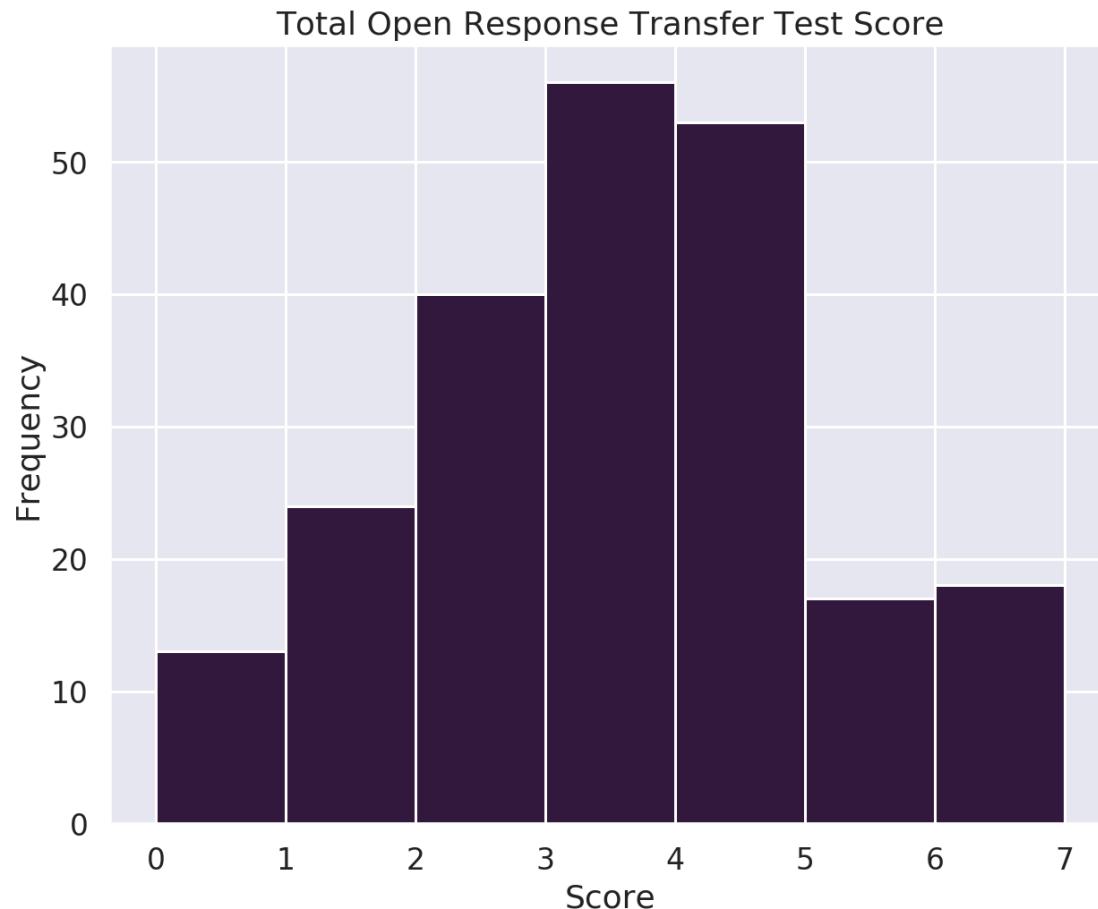
A star is 6 solar masses. If it were to explode in a supernova what would it produce? Please explain your reasoning.

What happens when a rocket leaves orbit and approaches the center of the black hole?

A supernova explosion produces a neutron star. Why didn't it make a black hole?

Imagine you are orbiting a black hole and the other space traveler moves closer to the black hole and comes back who has experienced **more** time passing?

Transfer



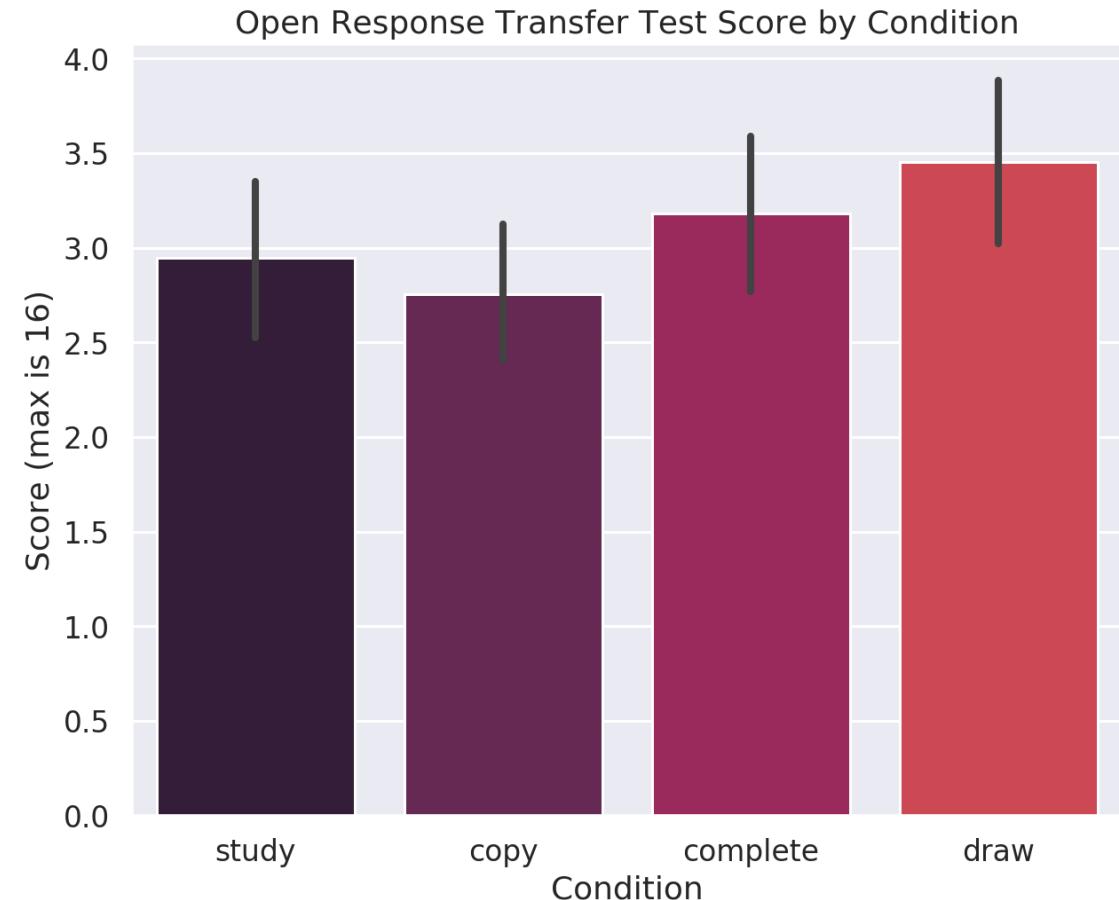
Transfer

Mean: 3.072

standard dev: 1.579

Min: 0 Median: 3.0

Max: 7



$F(3, 217) = 1.976, p = 0.118$

Measuring Cognitive Load

Intrinsic

“The topic/topics covered in the activity was/were very complex.”

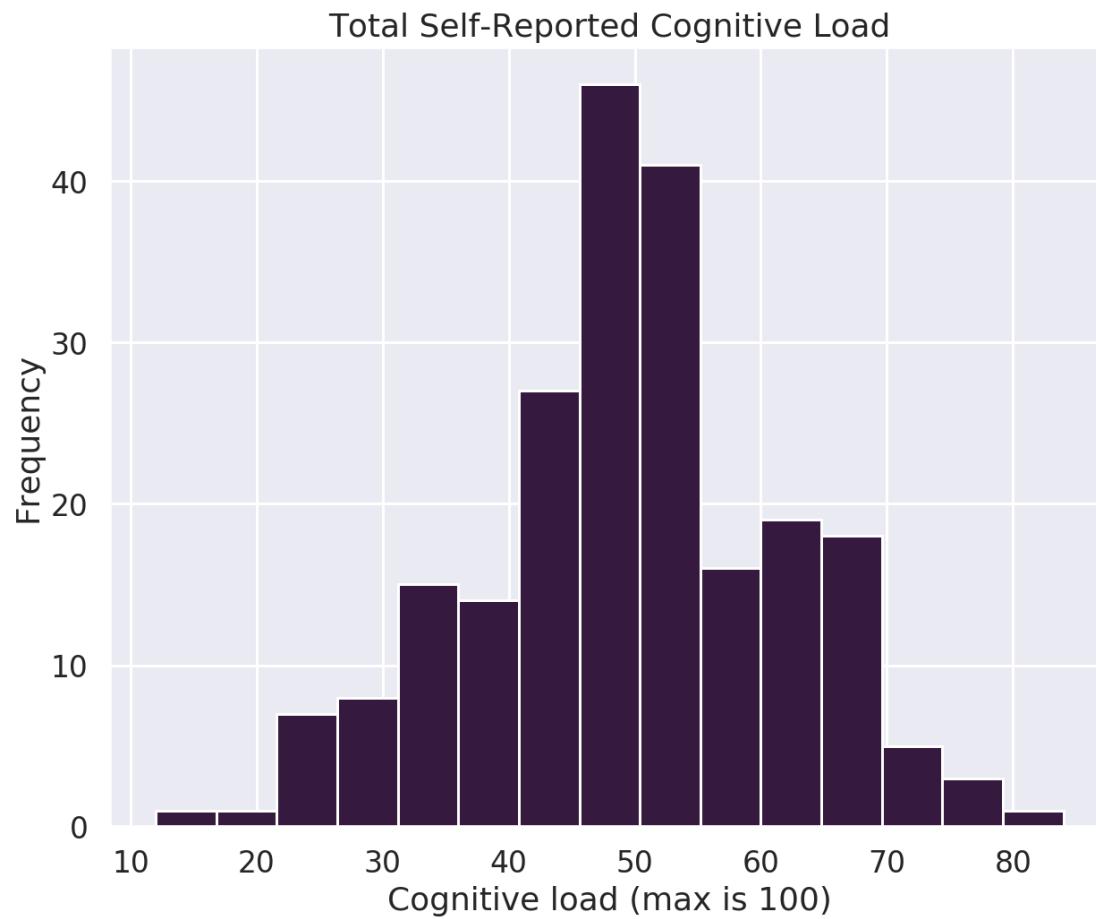
Extraneous

“The instructions and/or explanations during the activity were very unclear.”

Germane

“The activity really enhanced my understanding of the topic(s) covered.”

Total Cognitive Load (10 items)



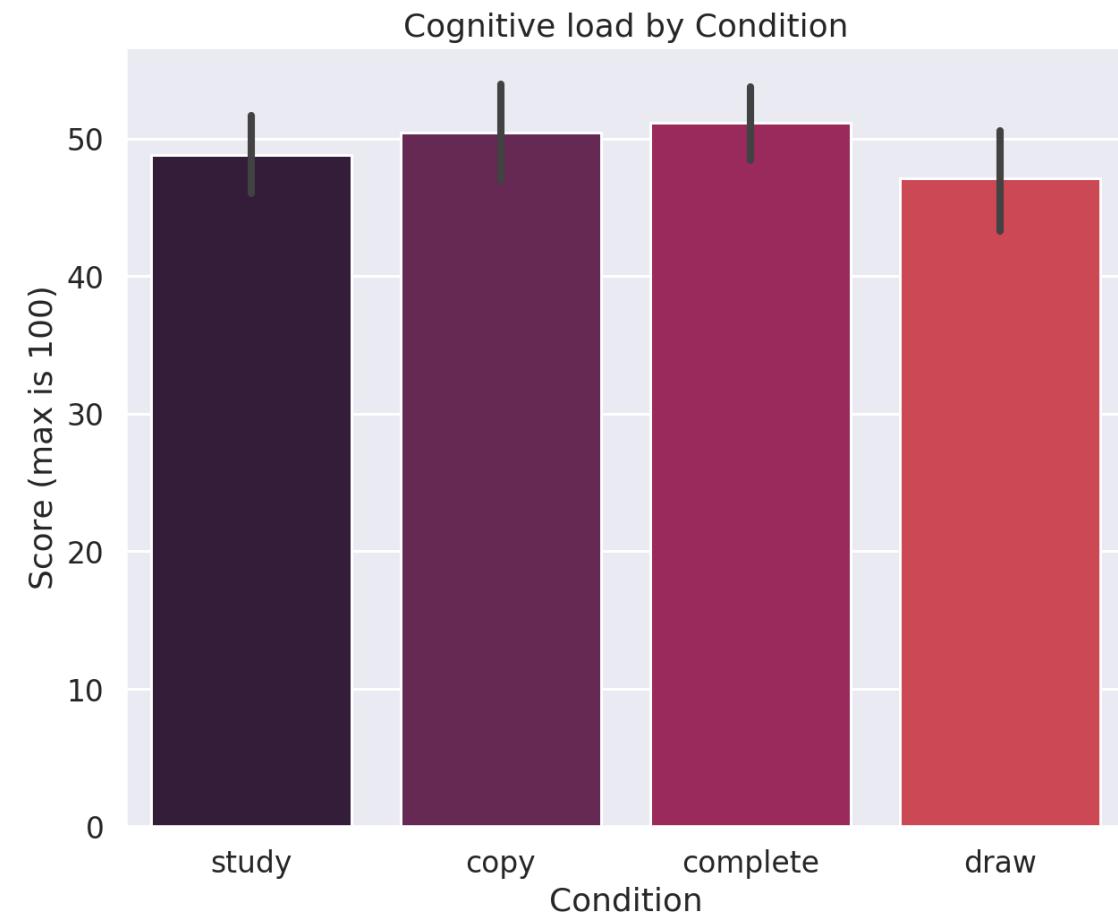
Mean: 49.335

Standard dev: 12.165

Min: 12

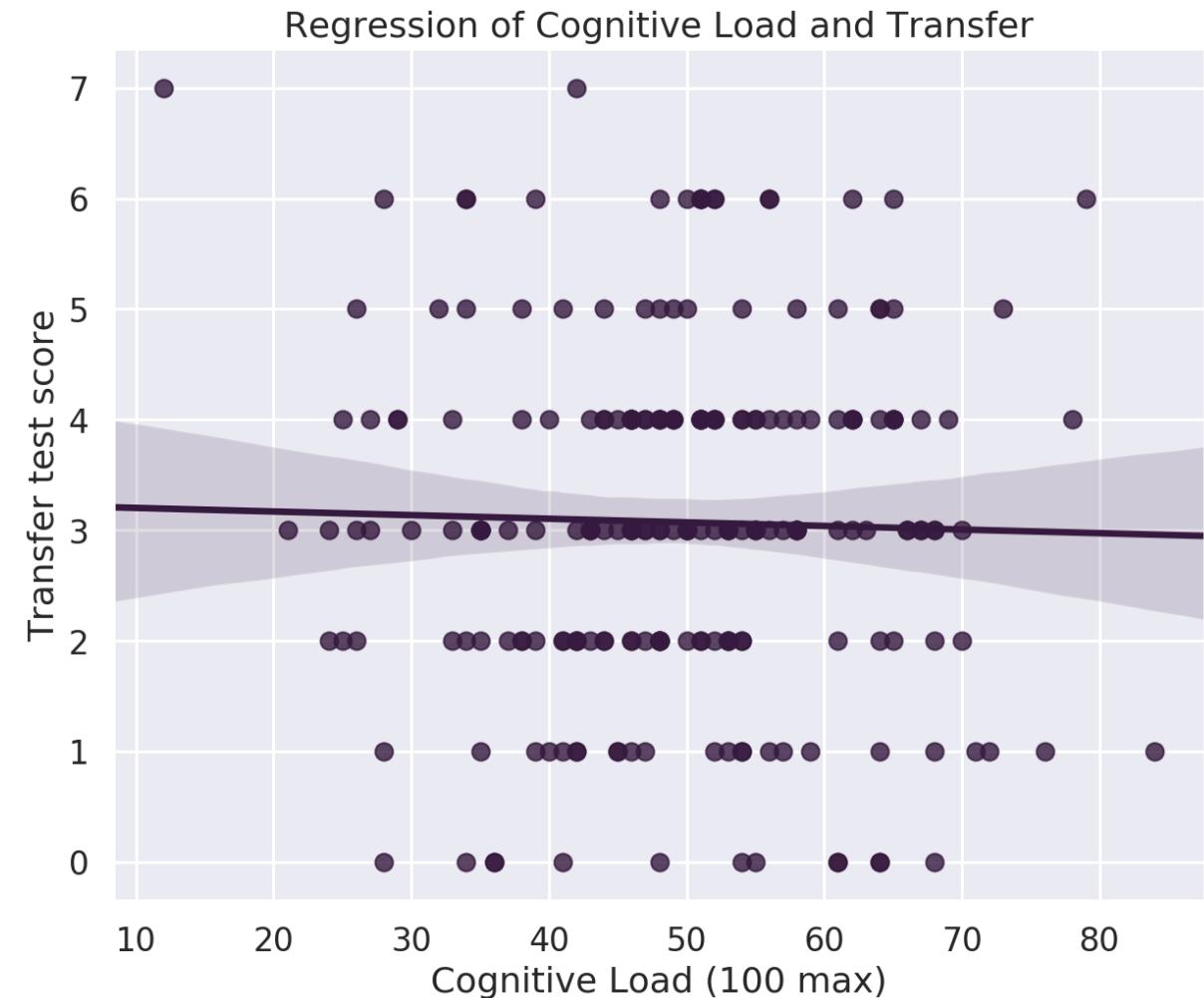
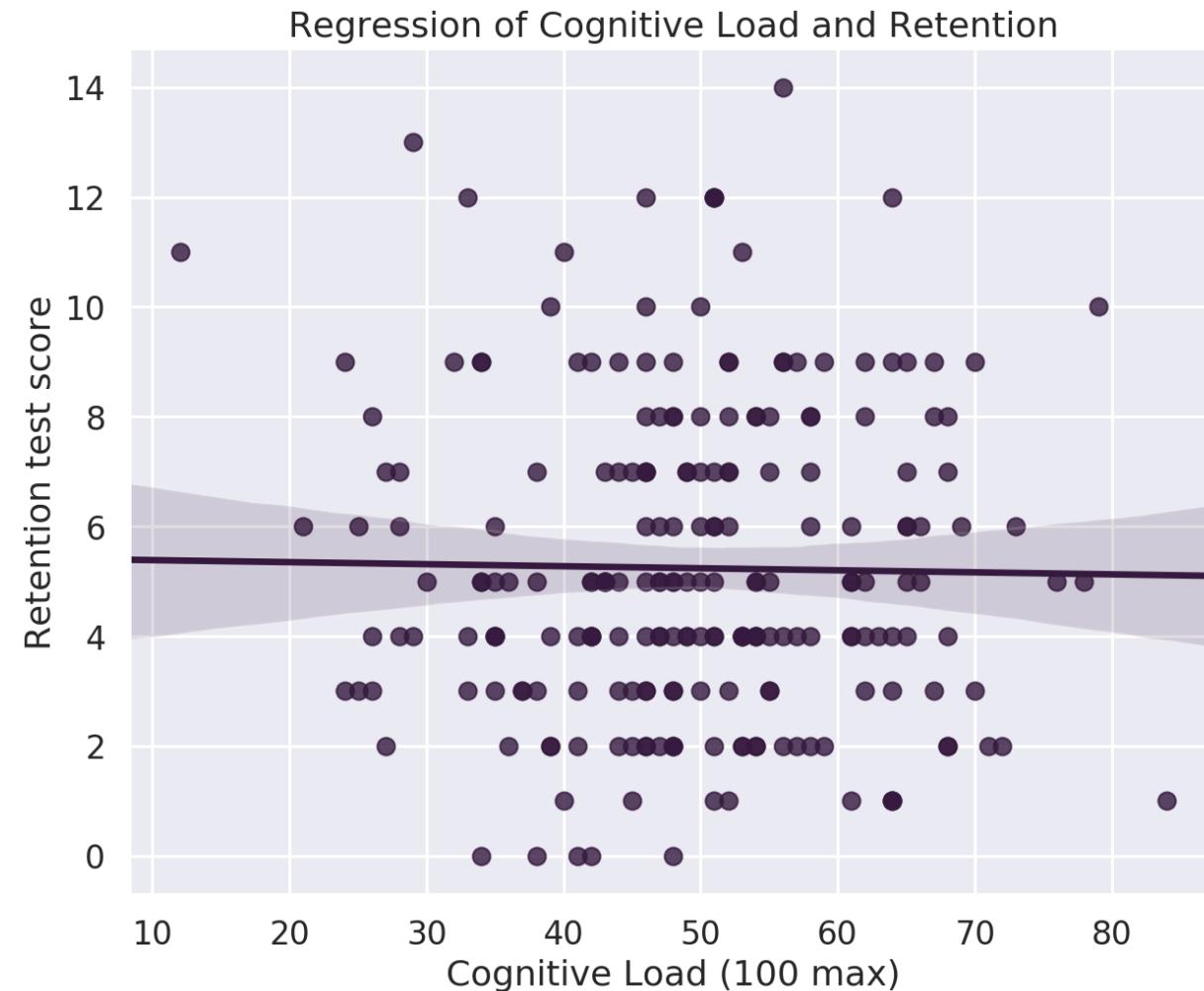
Median: 49.0

Max: 84

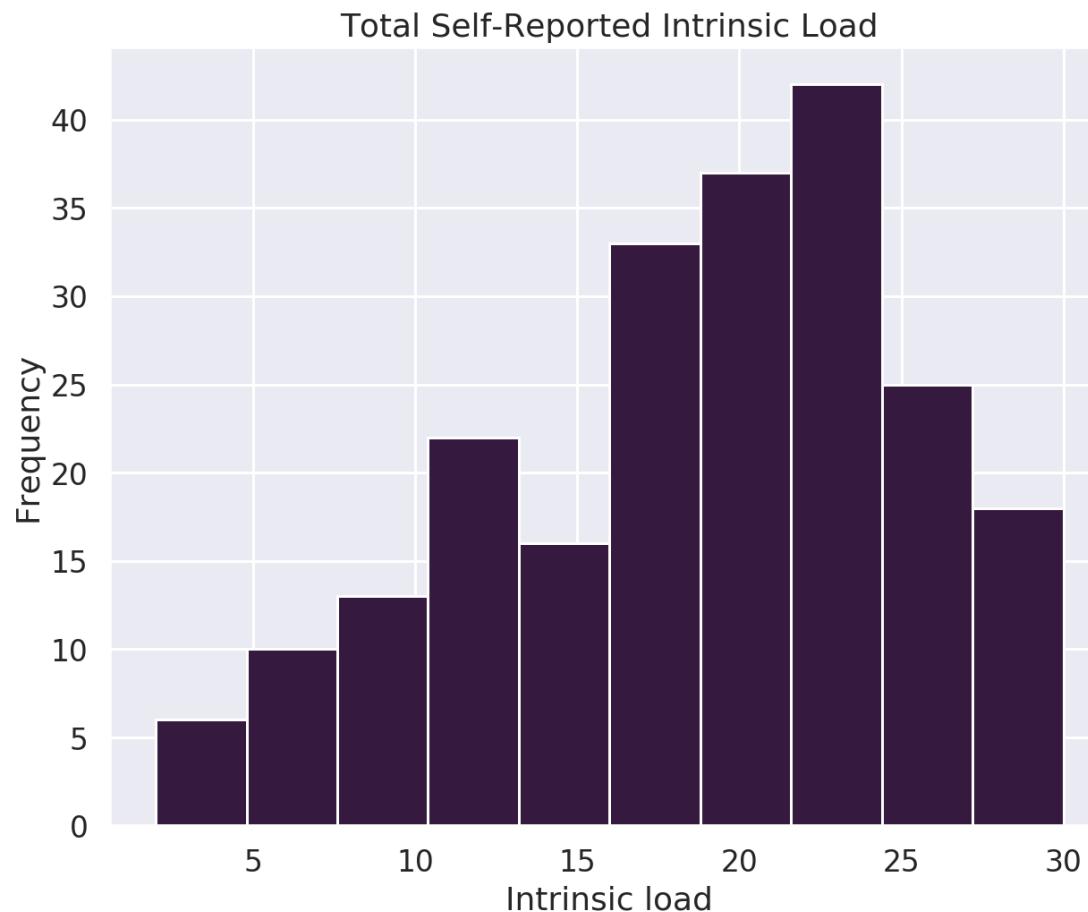


$$F(3, 217) = 1.238, p = 0.297$$

Regressions of Cognitive Load and Learning



Total Intrinsic Load (3 items)



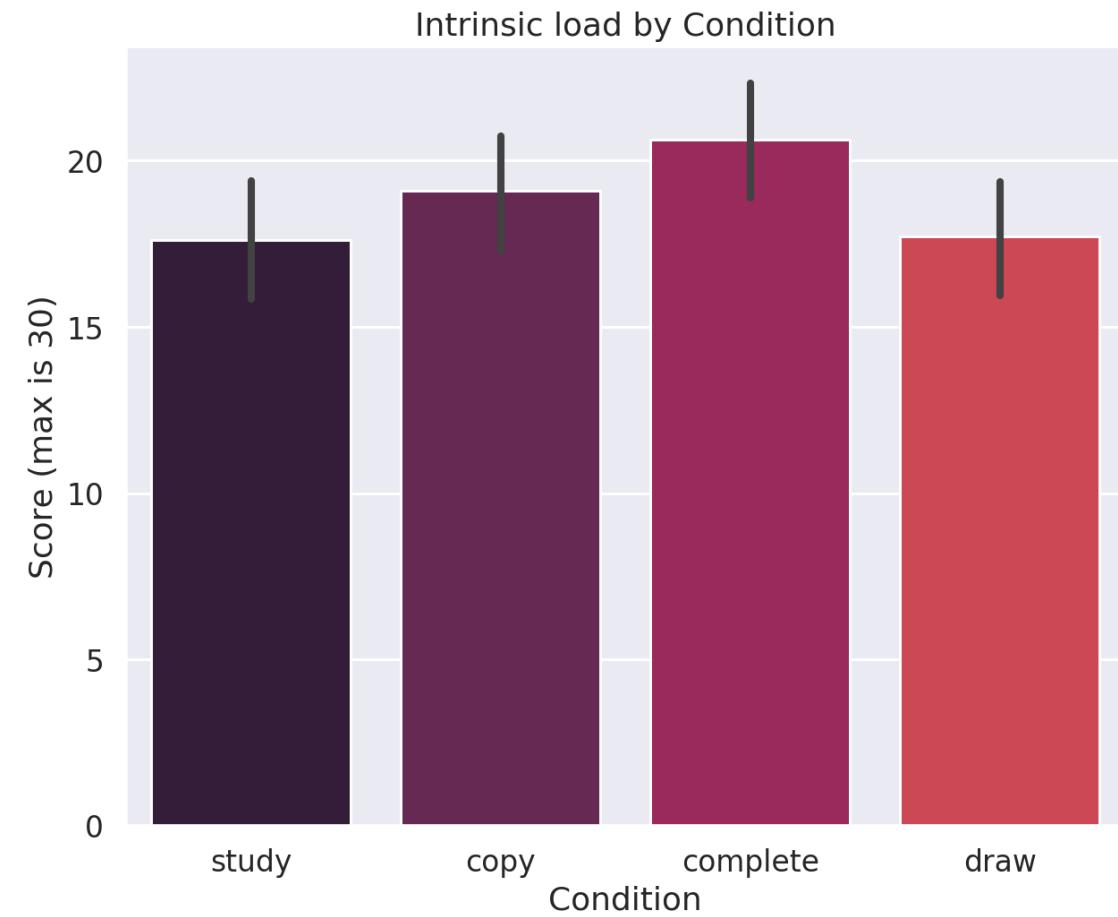
Intrinsic Load

Mean: 18.742

Standard dev: 6.719

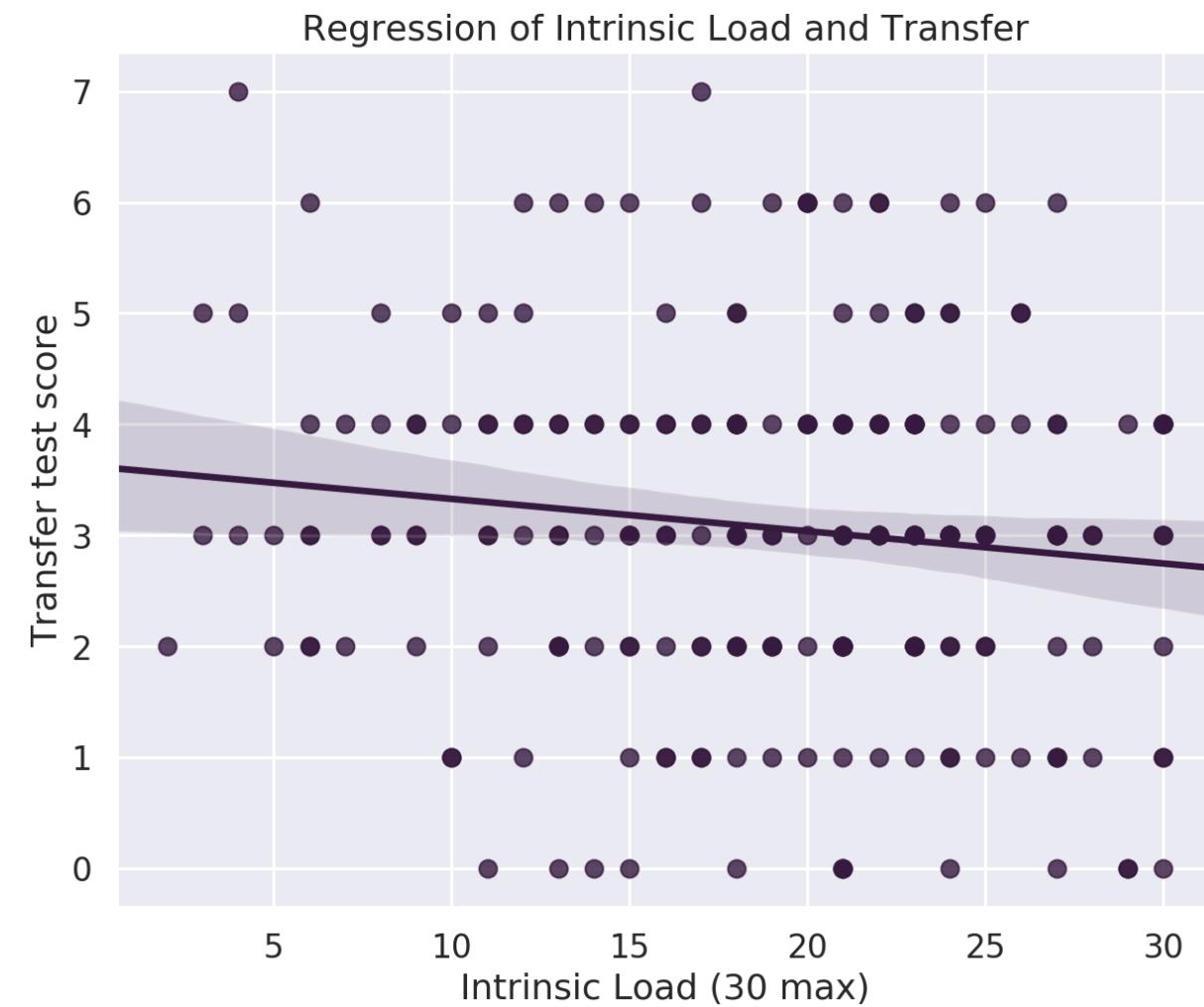
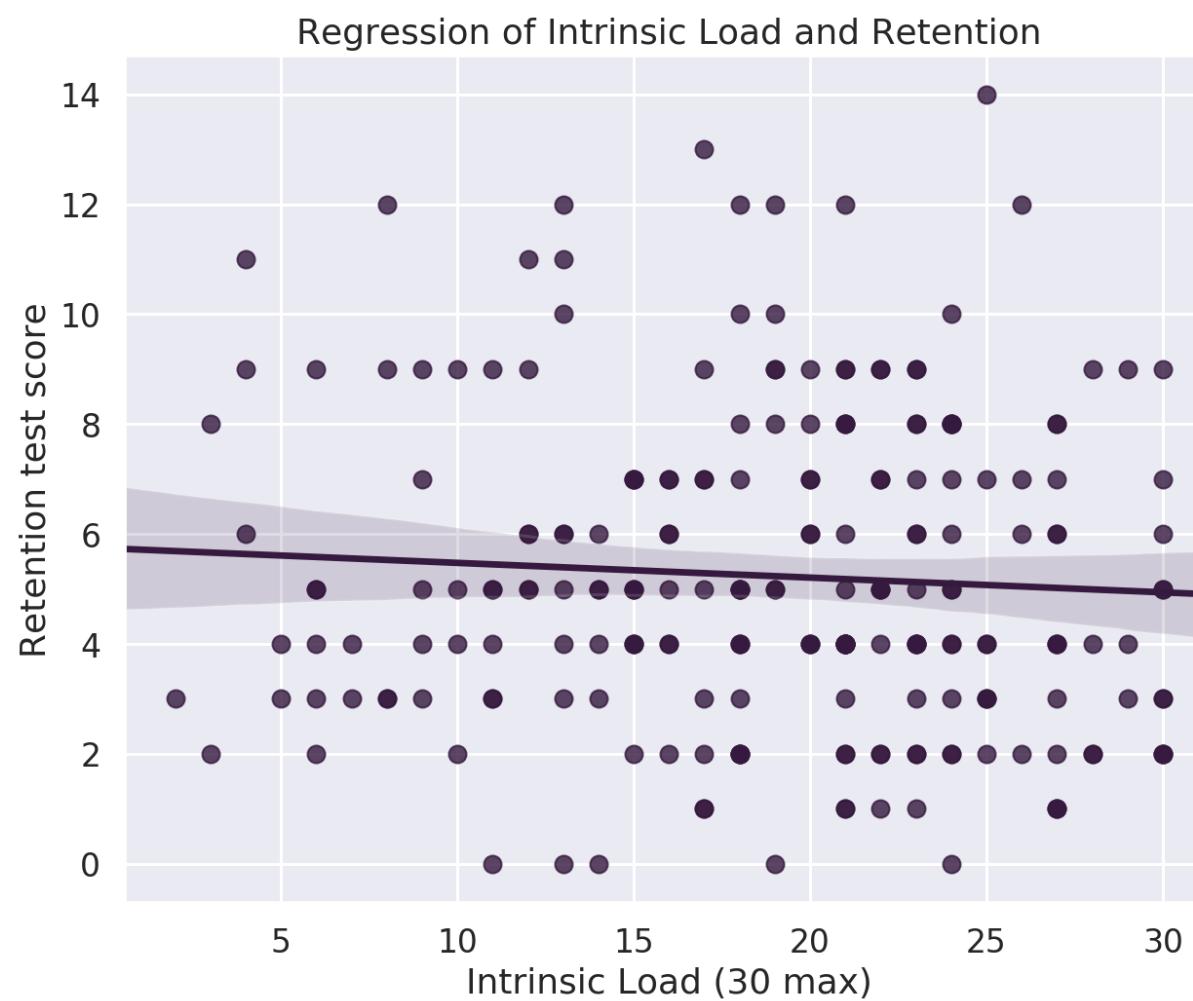
Min: 2 Median: 20.0

Max: 30

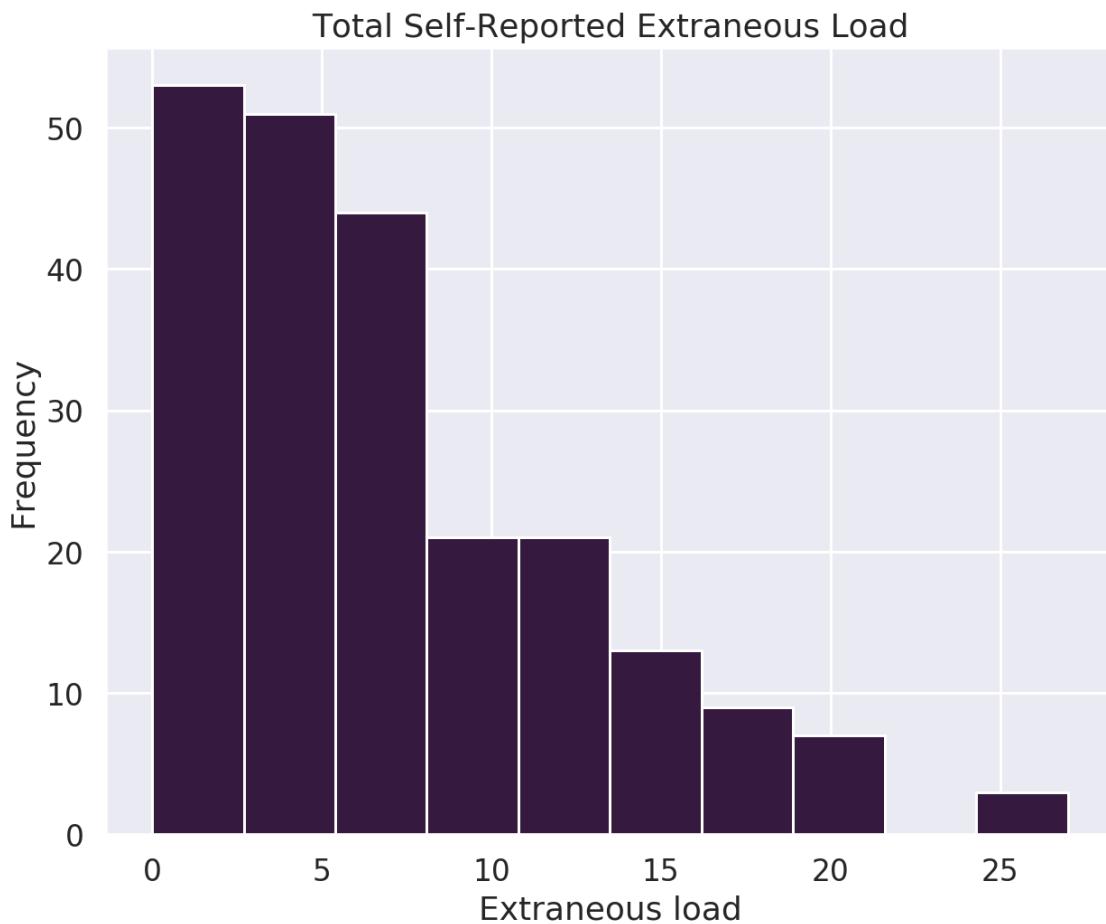


$$F(3, 217) = 2.736, p = 0.0445$$

Regressions of Intrinsic Load and Learning



Total Extraneous Load (3 items)



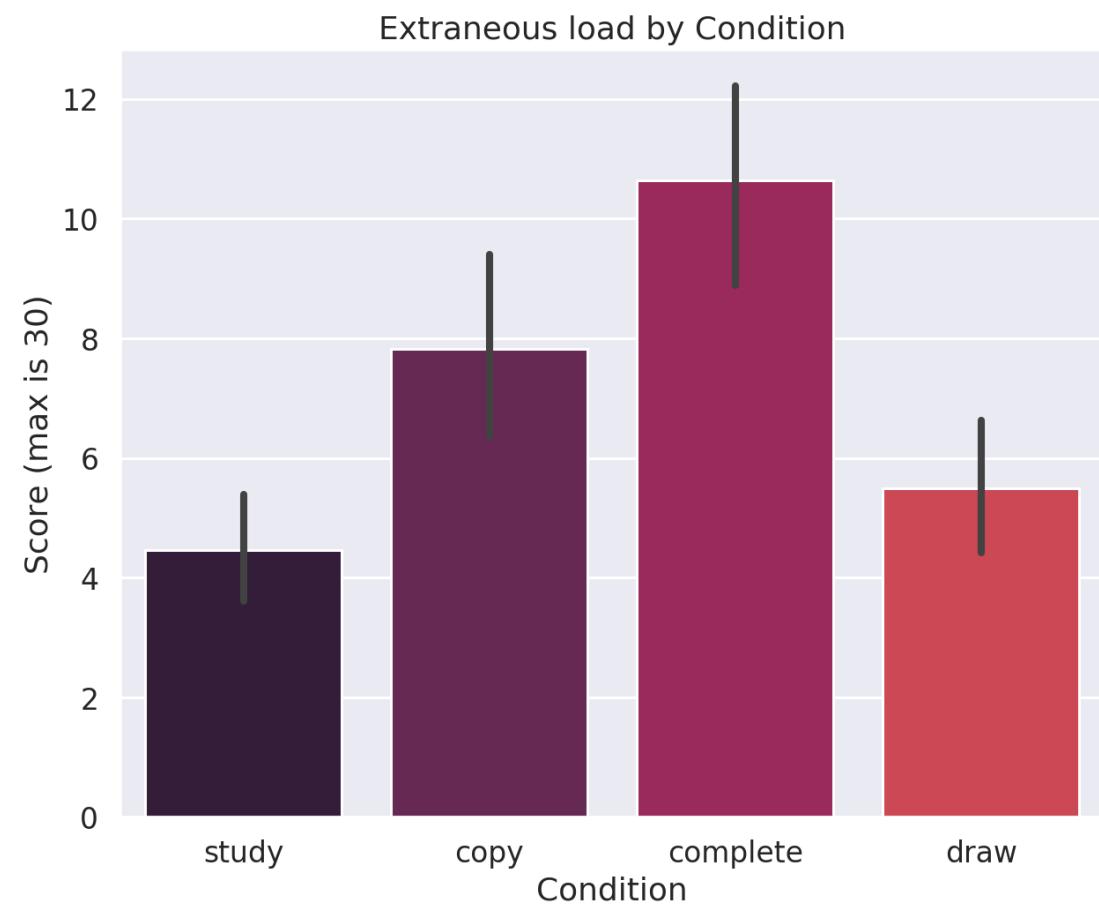
Extraneous Load

Mean: 7.136

Standard dev: 5.803

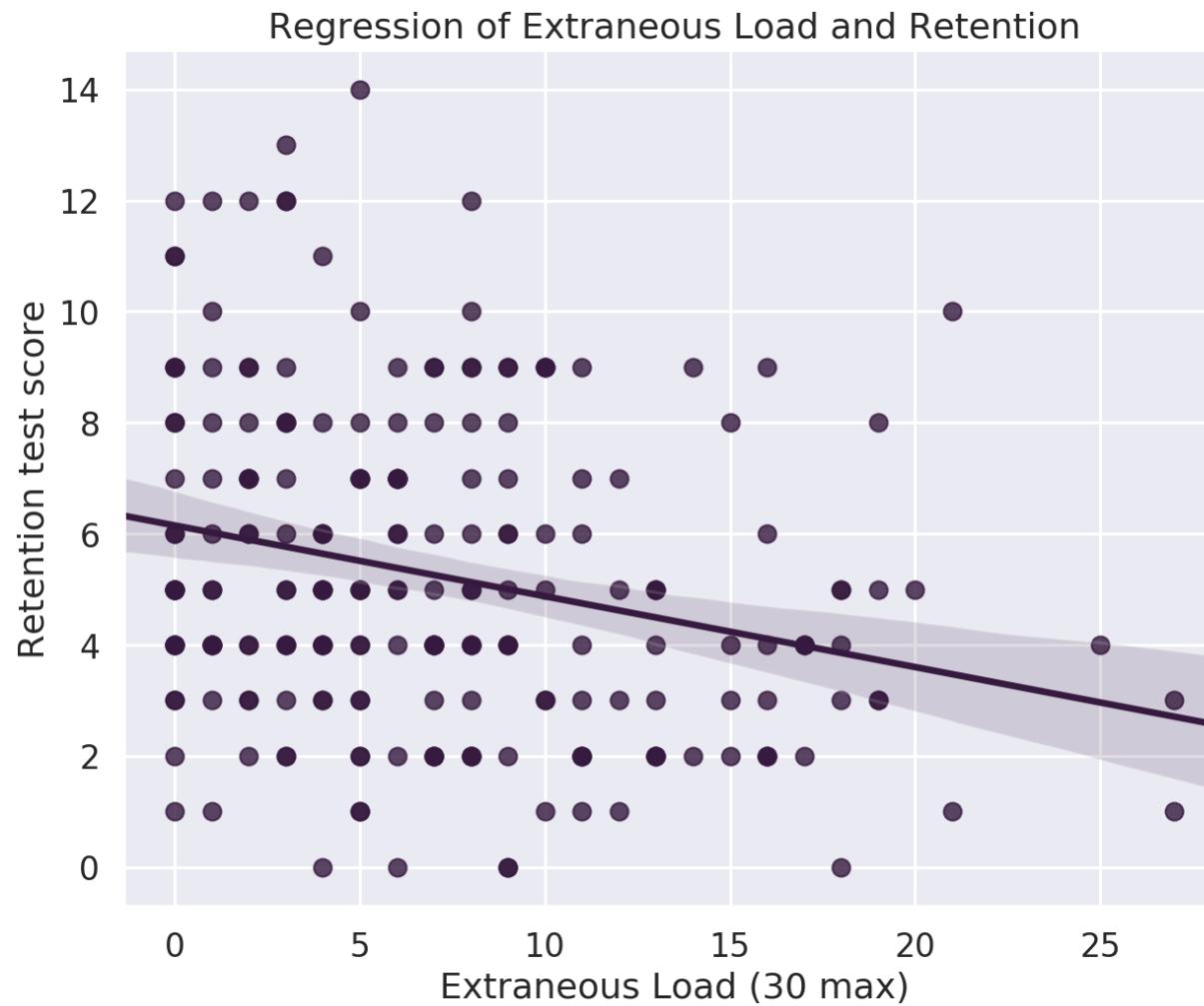
Min: 0 Median: 6.0

Max: 27

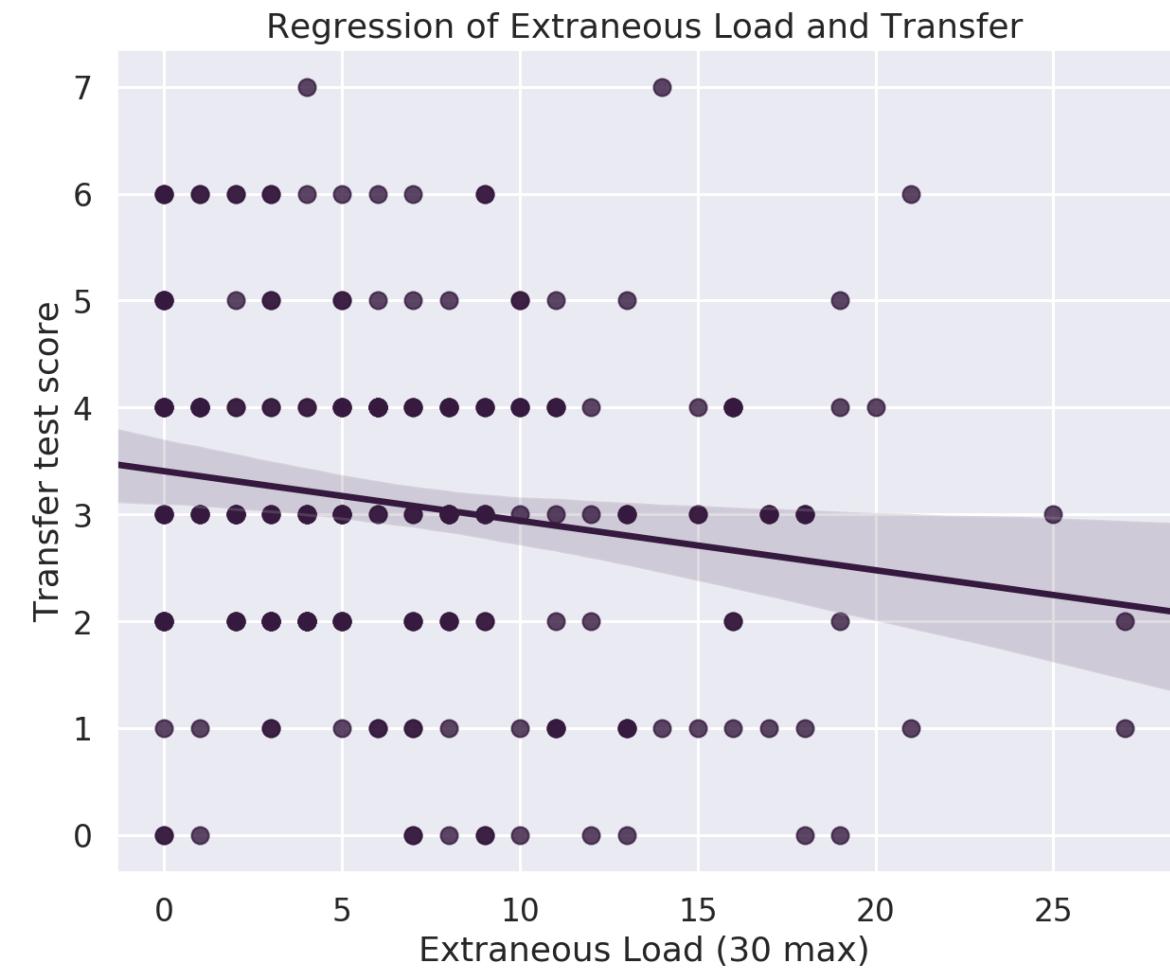


$$F(3, 217) = 14.79, p = 0.00000000846$$

Regressions of Extraneous Load and Learning

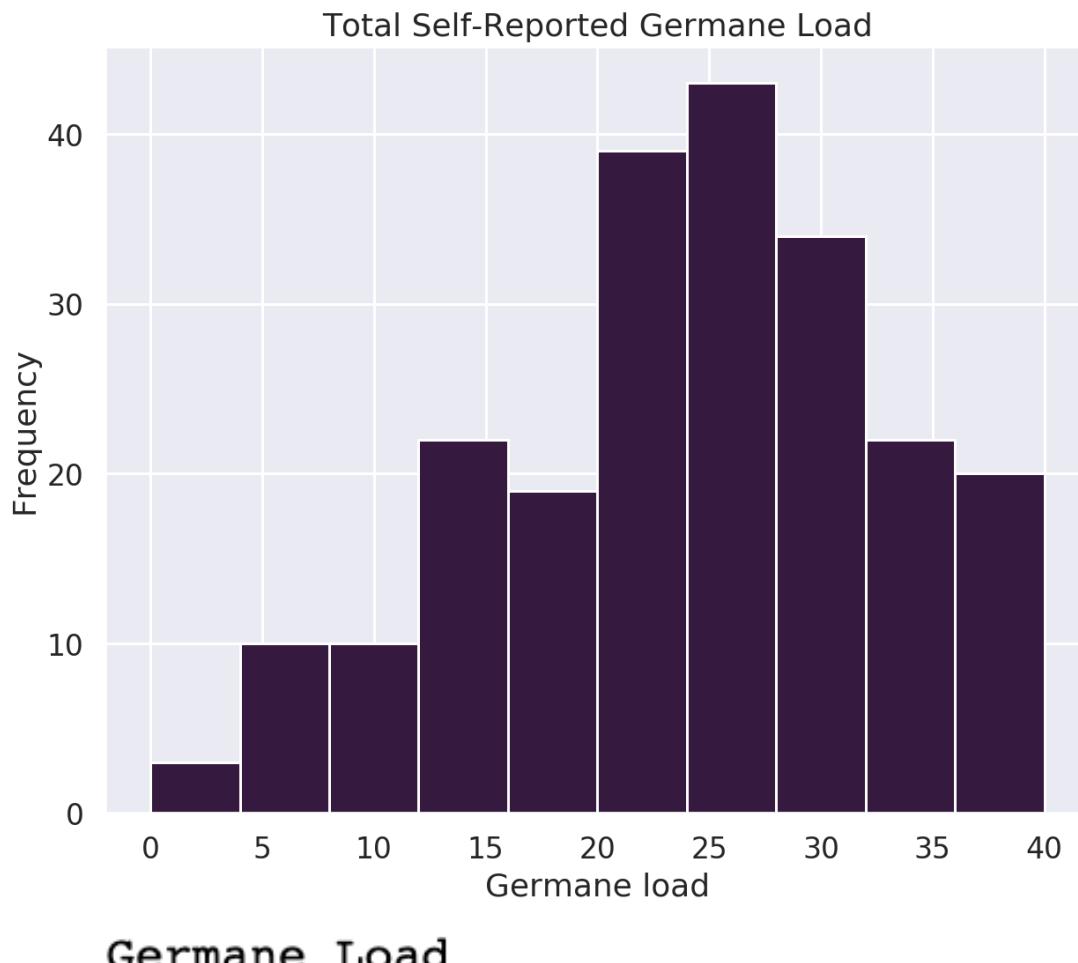


$F(1,219) = 15.52, p = 0.0001, R^2 = 6.62\%$



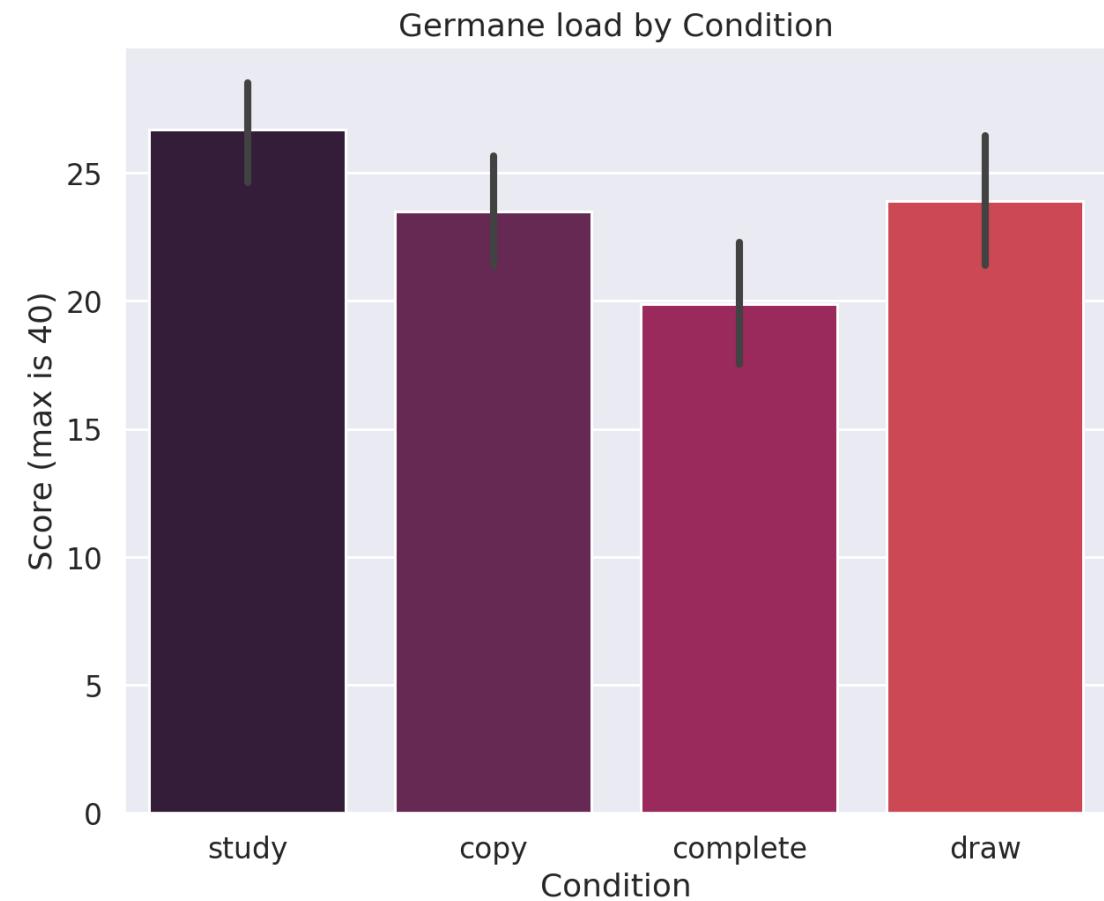
$F(1,219) = 6.53, p = 0.0113, R^2 = 2.45\%$

Total Germane Load (4 items)



Mean: 23.457 Standard dev: 8.948

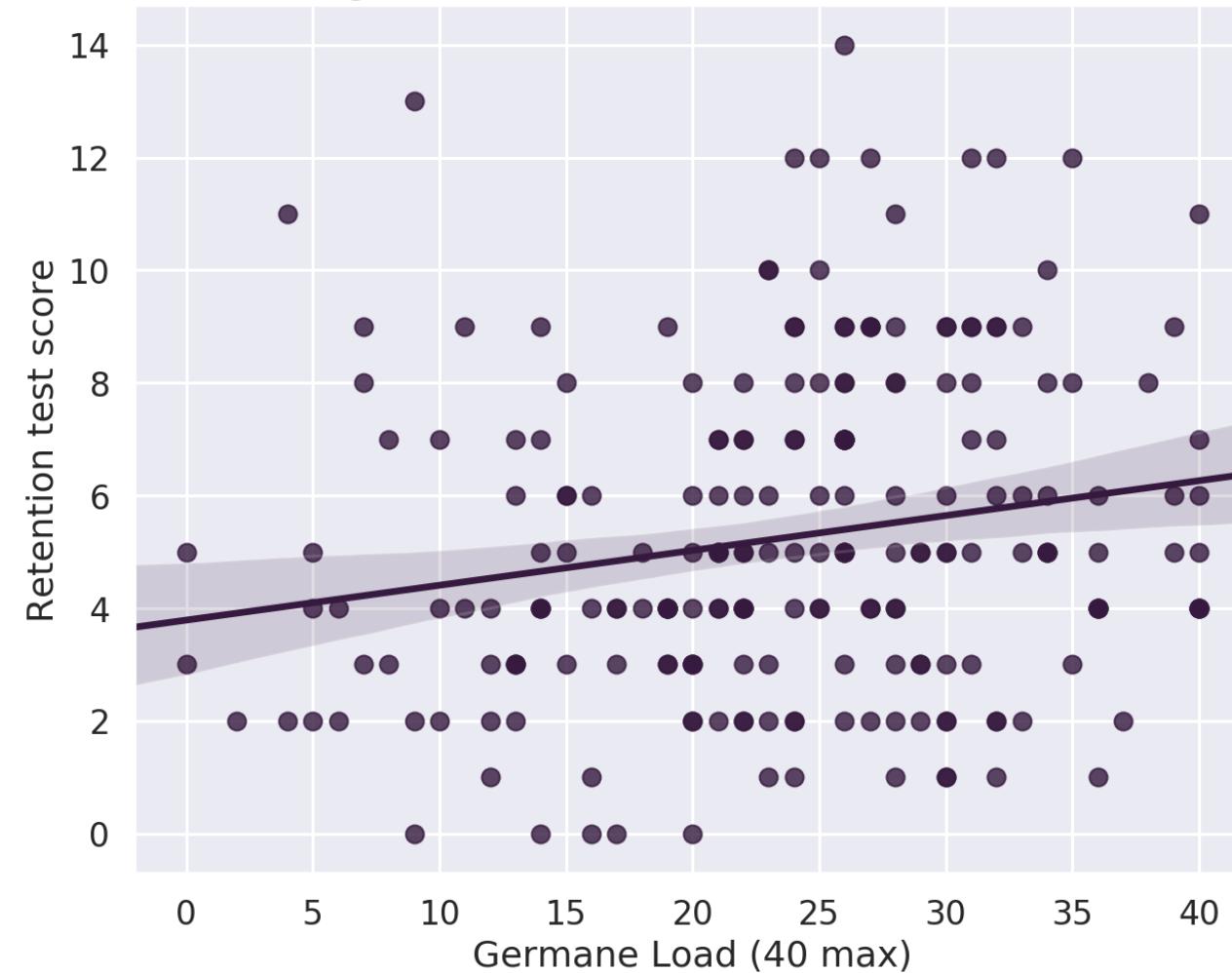
Min: 0 Median: 24.0 Max: 40



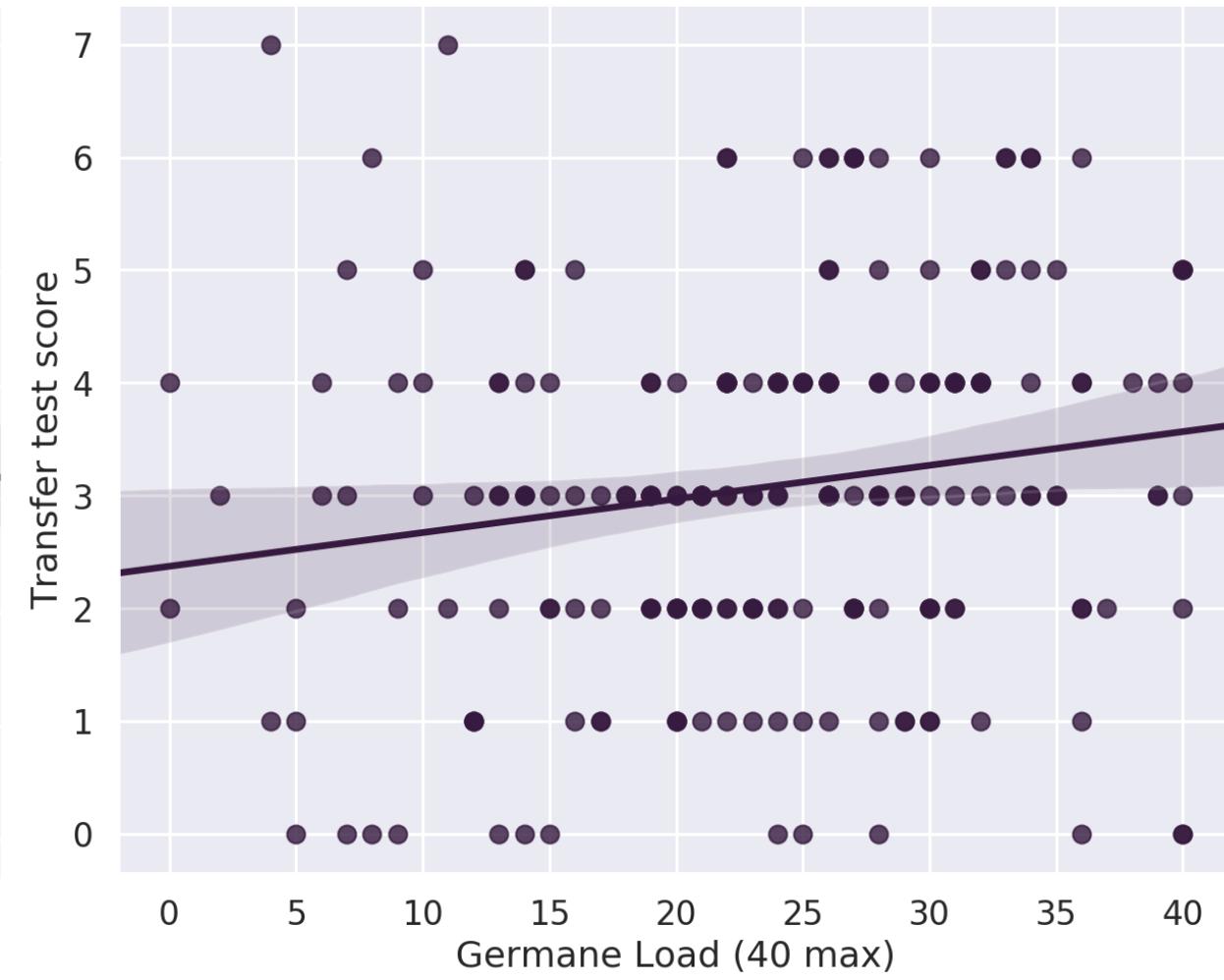
$F(3, 217) = 5.718, p = 0.000875$

Regressions of Germane Load and Learning

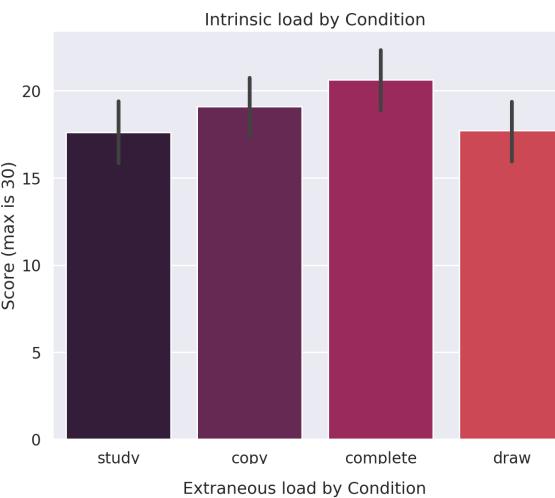
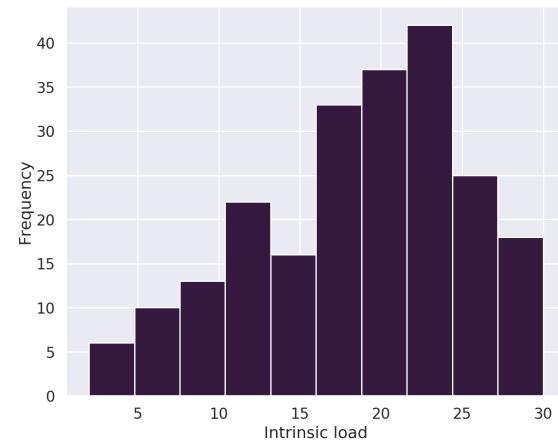
Regression of Germane Load and Retention



Regression of Germane Load and Transfer

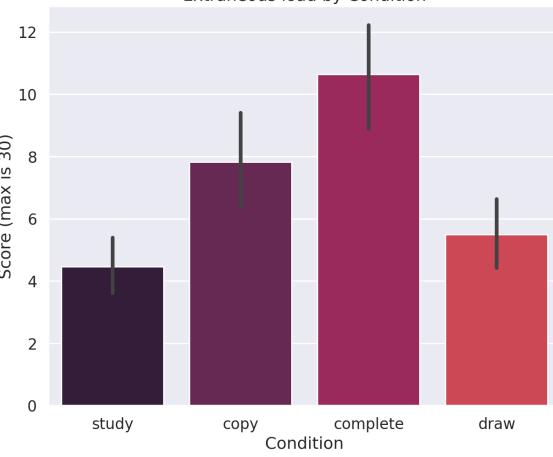
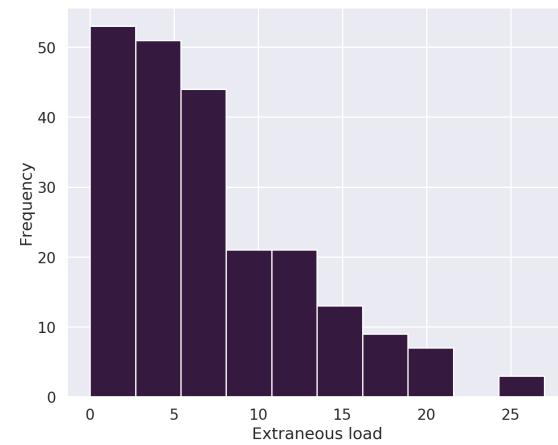


IL



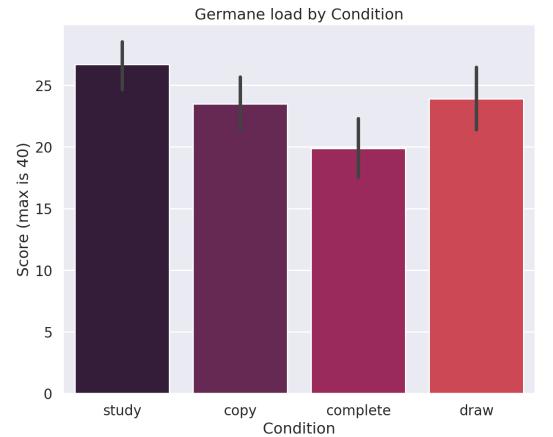
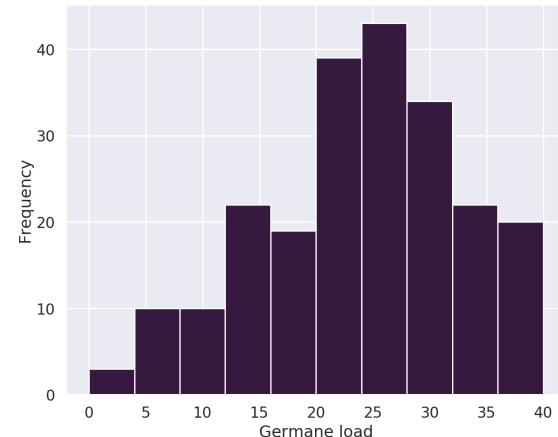
$$F(3, 217) = 2.736, p = 0.0445$$

EL



$$F(3, 217) = 14.79, p = 0.00000000846$$

GL



$$F(3, 217) = 5.718, p = 0.000875$$

Figure A: The "size" of a black hole is defined by the radius of its event horizon, the Schwarzschild radius.

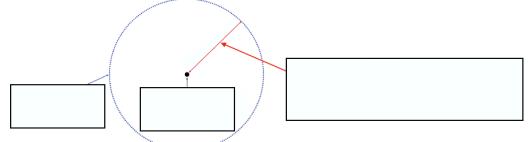


Figure B: As mass increases the distortion of spacetime increases.



As mass inc.

Please rate how much you enjoyed the drawing task.

- Liked a great deal
- Liked somewhat
- Neither liked nor disliked
- Disliked somewhat
- Disliked a great deal

Figure C: As mass reaches the event horizon, the grid reaches the edge of the black hole.

```
## Unique and Total Word Calculator
size = len(values) # gives the number of rows(i.e., cells in this case) which is 238
n=1 # we want to start from cell 0, the first increment would make the -1 a 0
lst_words = []
lst_2_words = []

while True:
    n += 1
    if n == size:
        break

    # inspect the next cell
    print ("-" * 35, "cell " + str(n), "-" * 35)
    text = values[n][0]
    text_str = str(text).lower()
    no_punct_str = remove_punctuation(text_str)

    d = {} # initialize an empty dictionary
    for word in no_punct_str.split():
        try:
            d[word] += 1 # the entry exists
        except KeyError:
            d[word] = 1 # a new entry

    uqs = [] # will hold the list of unique words for each cell
    for k in d.keys():
        if d[k] == 1:
            uqs.append(k)
    lst_words.append(len(uqs)) # append the number of unique words

    d2 = {} # initialize an empty dictionary
    wrds = [] #will hold the list of total words for each cell
    for word in no_punct_str.split():
        wrds.append(word)
    lst_2_words.append(len(wrds))
    # I am just printing the list of unique words.

    print ("The text in this cell:\n", text, "\n")
    print ("The number of words in this cell:\n", len(wrds), '\n\n')
    print ("unique words in this cell:\n", uqs, '\n\n')
    print ("The number of unique words in this cell:\n", len(uqs), '\n\n')
```

A black hole is an indefinite space. It is named black because no light can escape a hole because it is seen as a hole through a telescope. Its center is made up of neutrons. Two stars collapse. The black is made up of a center (a ball of neutrons), a Schwarzschild radius that helps approximate the size of the black hole and an external horizon which separates the inside of the black hole with the outside of space. singularity is the enlargement of a center because it is infinite in time

The number of words in this cell:
89

unique words in this cell:
['an', 'indefinite', 'space', 'named', 'no', 'light', 'can', 'escape', 'seen', 'as', 'through', 'telescope', 'its', 'neutron', 'two', 'stars', 'collapse', 'the', 'ball', 'neutrons', 'schwarzschild', 'radius', 'that', 'helps', 'approximate', 'seize', 'external', 'horizon', 'which', 'separates', 'inside', 'with', 'outside', 'space', 'singularity', 'enlargement', 'infinite', 'in', 'time']

The number of unique words in this cell:
36

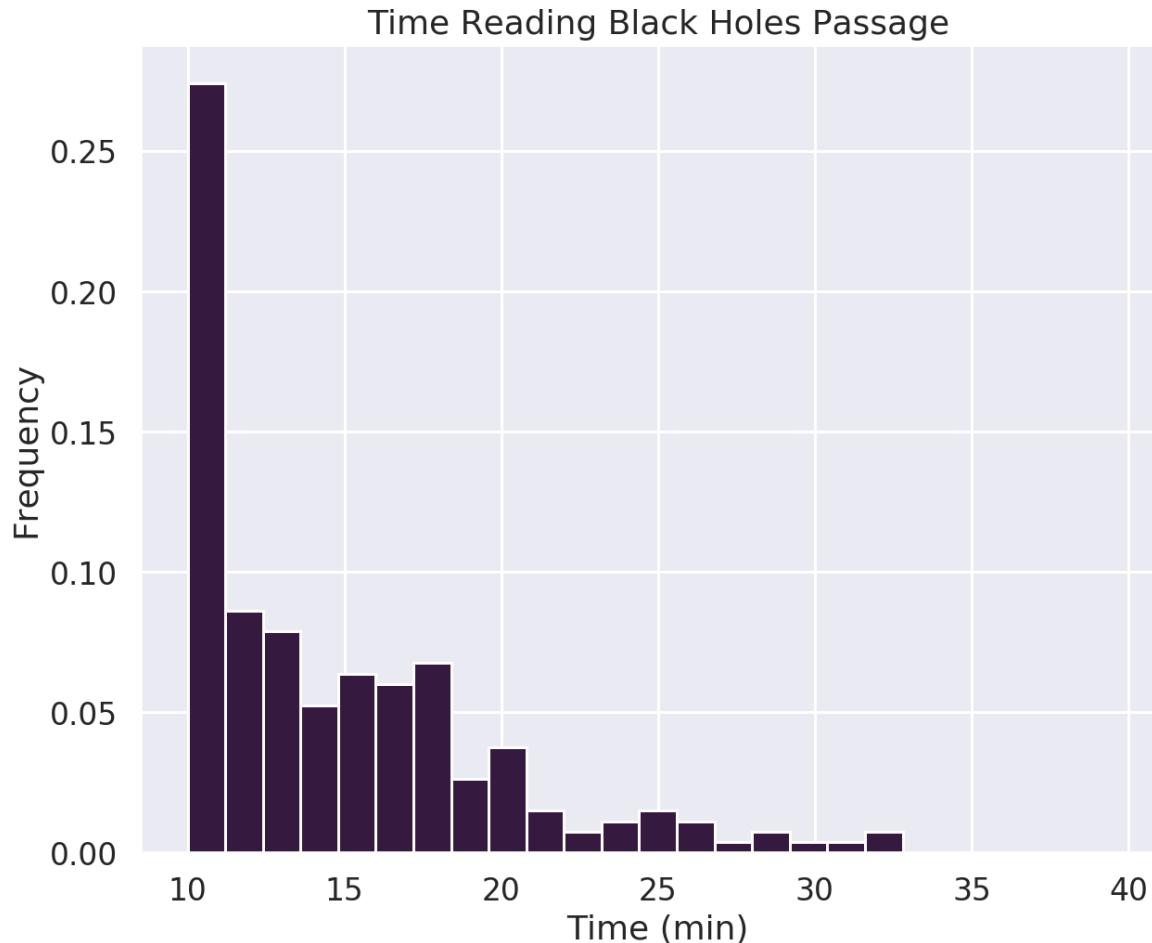
Extra Analyses

- ❖ Role of prior knowledge
- ❖ Time spent reading
- ❖ Condition enjoyment
- ❖ Word use
 - Total
 - Unique

Regressions of Prior Knowledge and Learning



Time Spent Engaging with Learning Materials



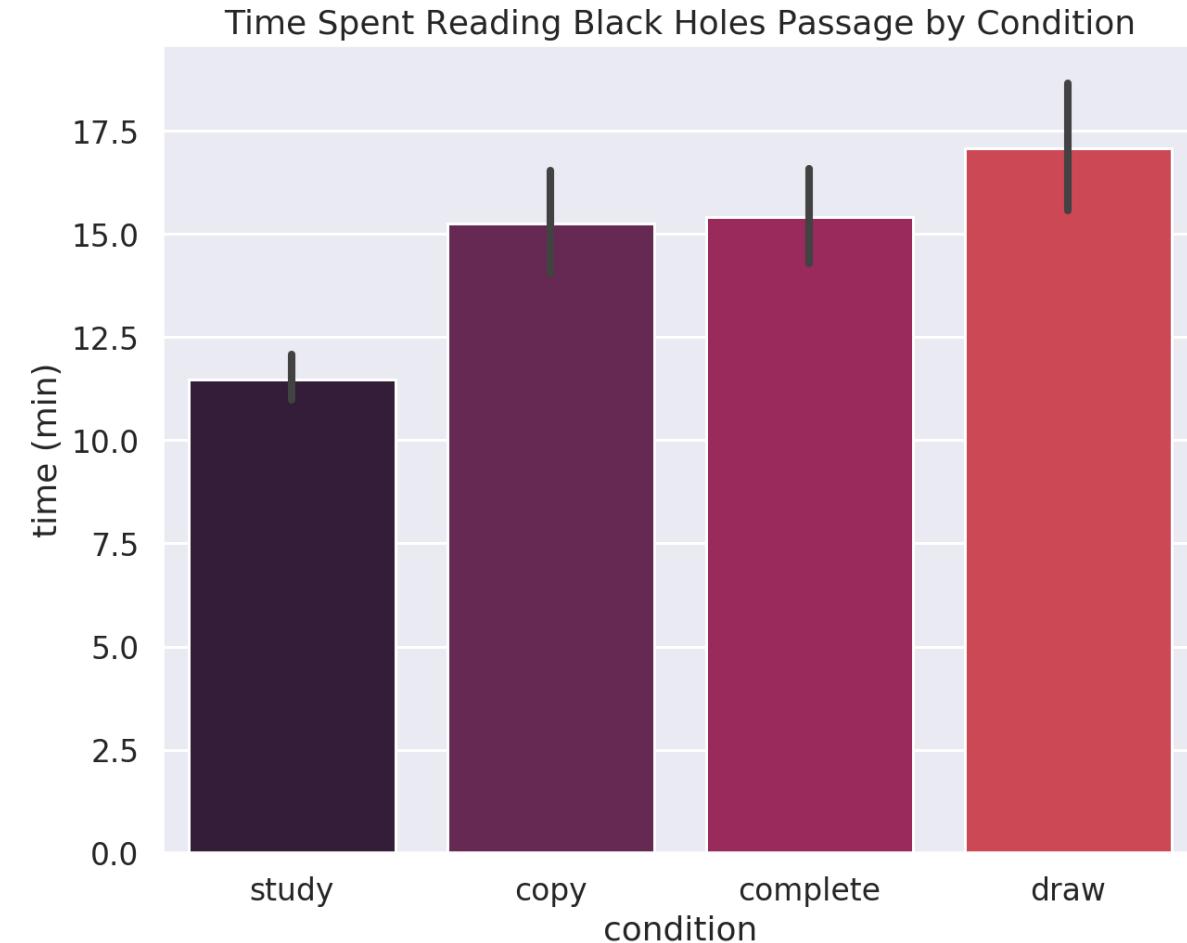
Time reading summary

Mean: 14.73

Standard dev: 4.889

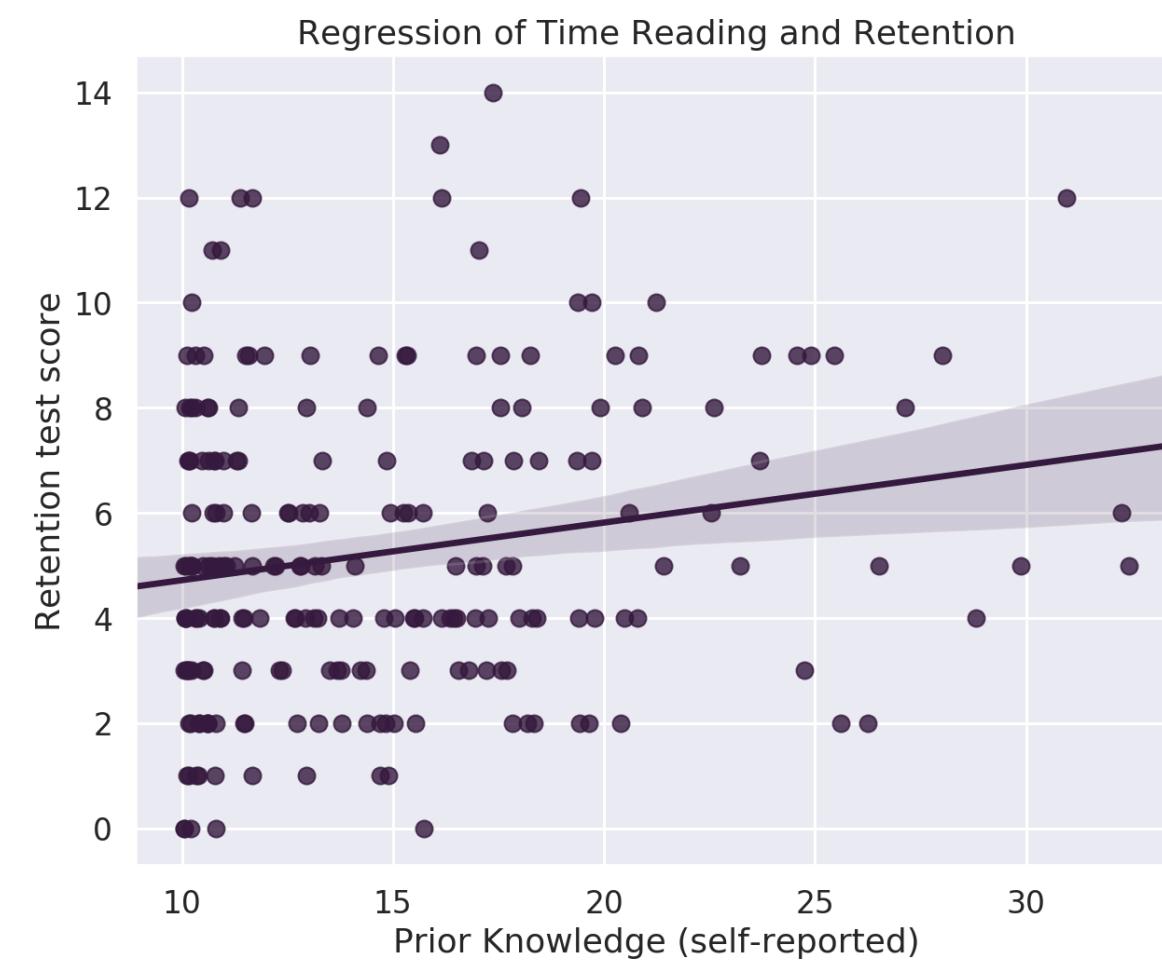
Min: 10.046

Median: 13.181 Max: 32.437

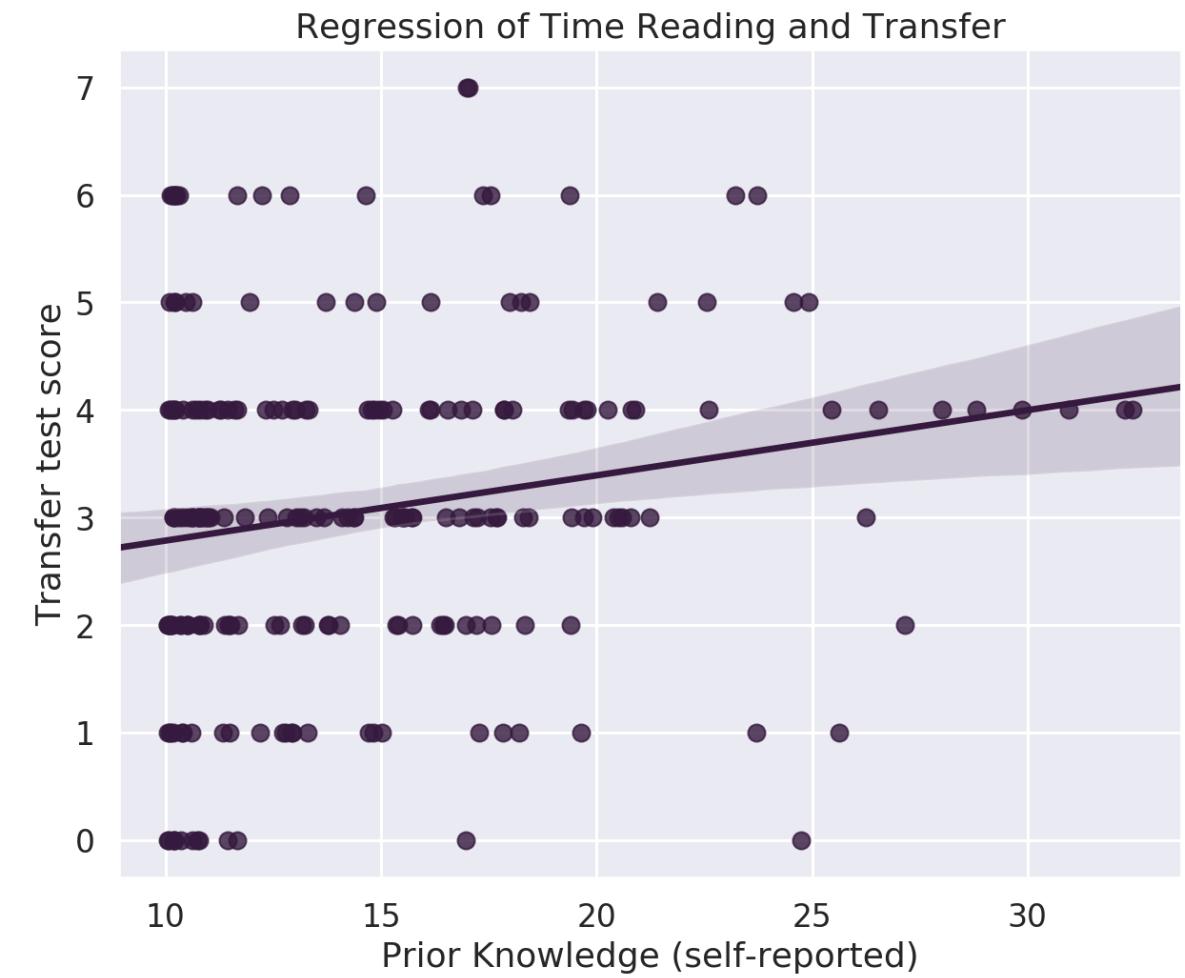


$F(3, 217) = 15.41, p = 0.000000004$

Regressions of Time Spent Engaging with Learning Materials

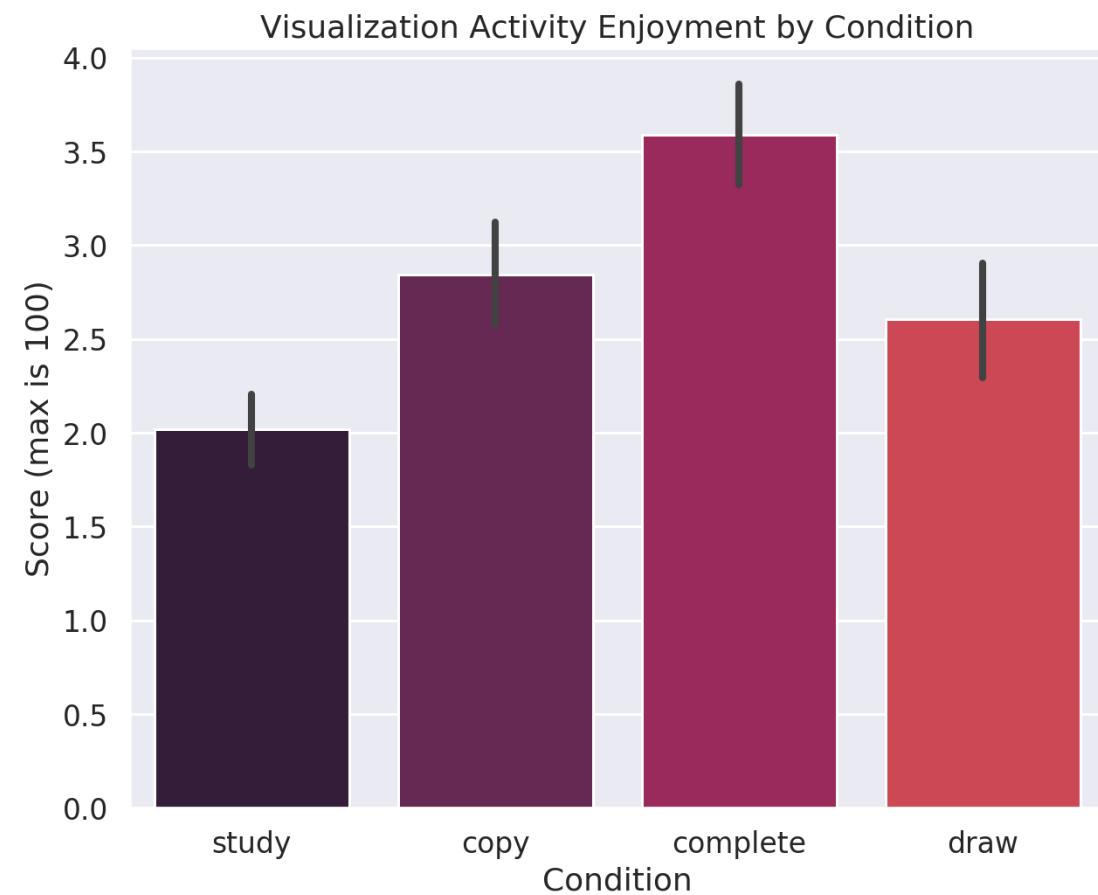
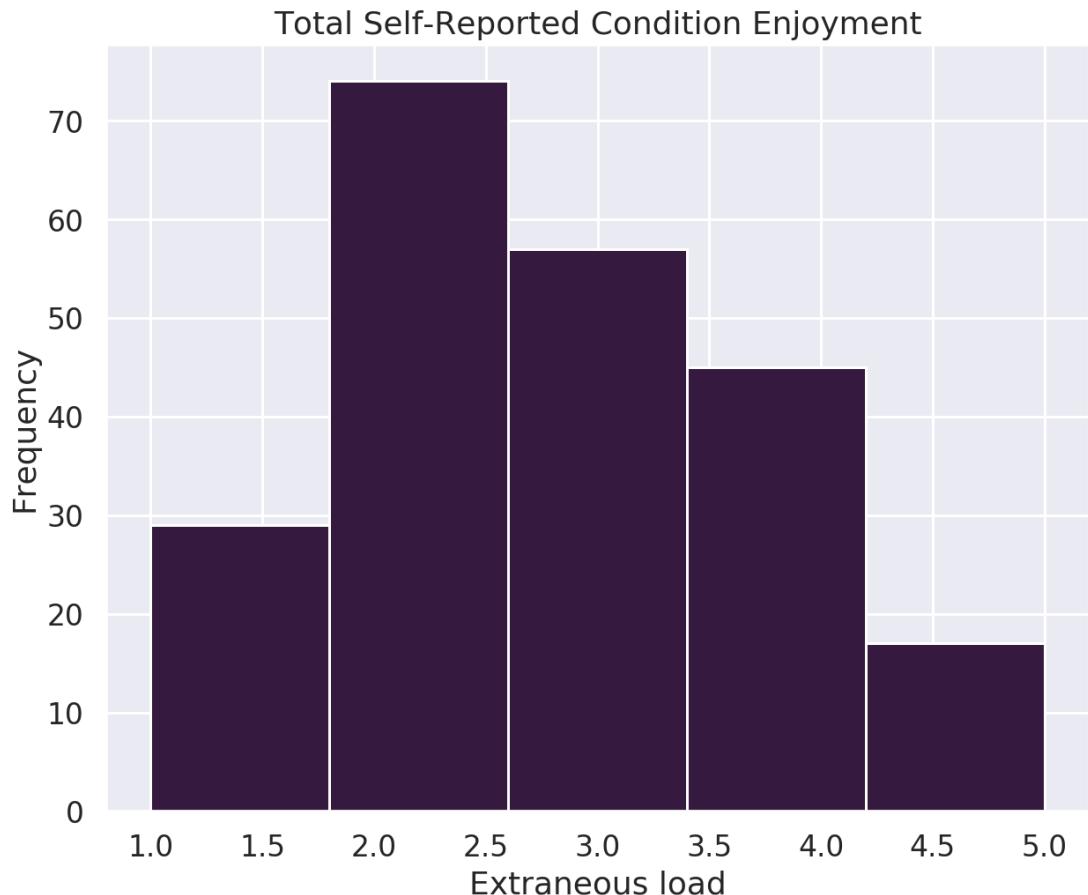


$F(1,219) = 7.90, P = 0.0054, R^2 = 3.48\%$



$F(1,219) = 8.03, P = 0.0050, R^2 = 3.54\%$

Condition Enjoyment

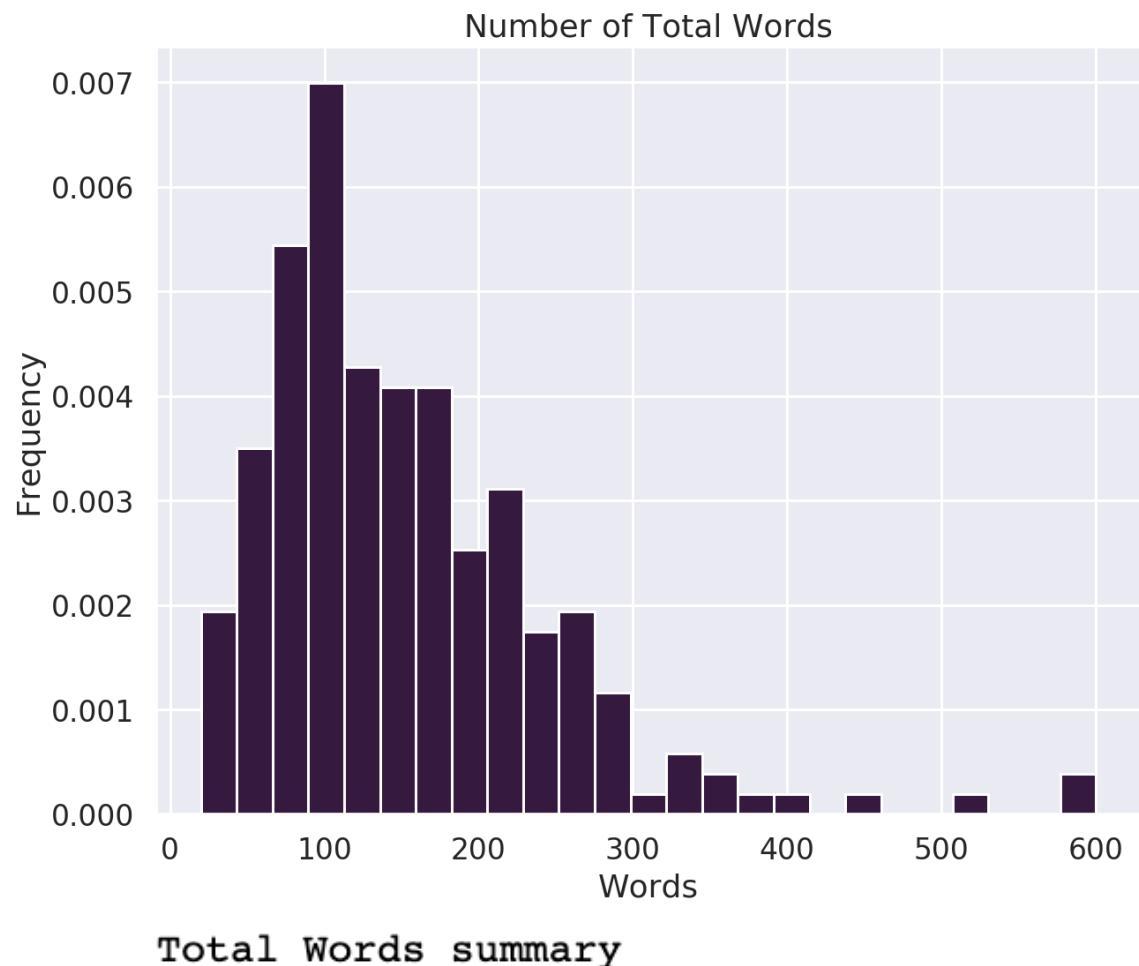


Condition Enjoyment

Mean: 2.761 standard dev: 1.146

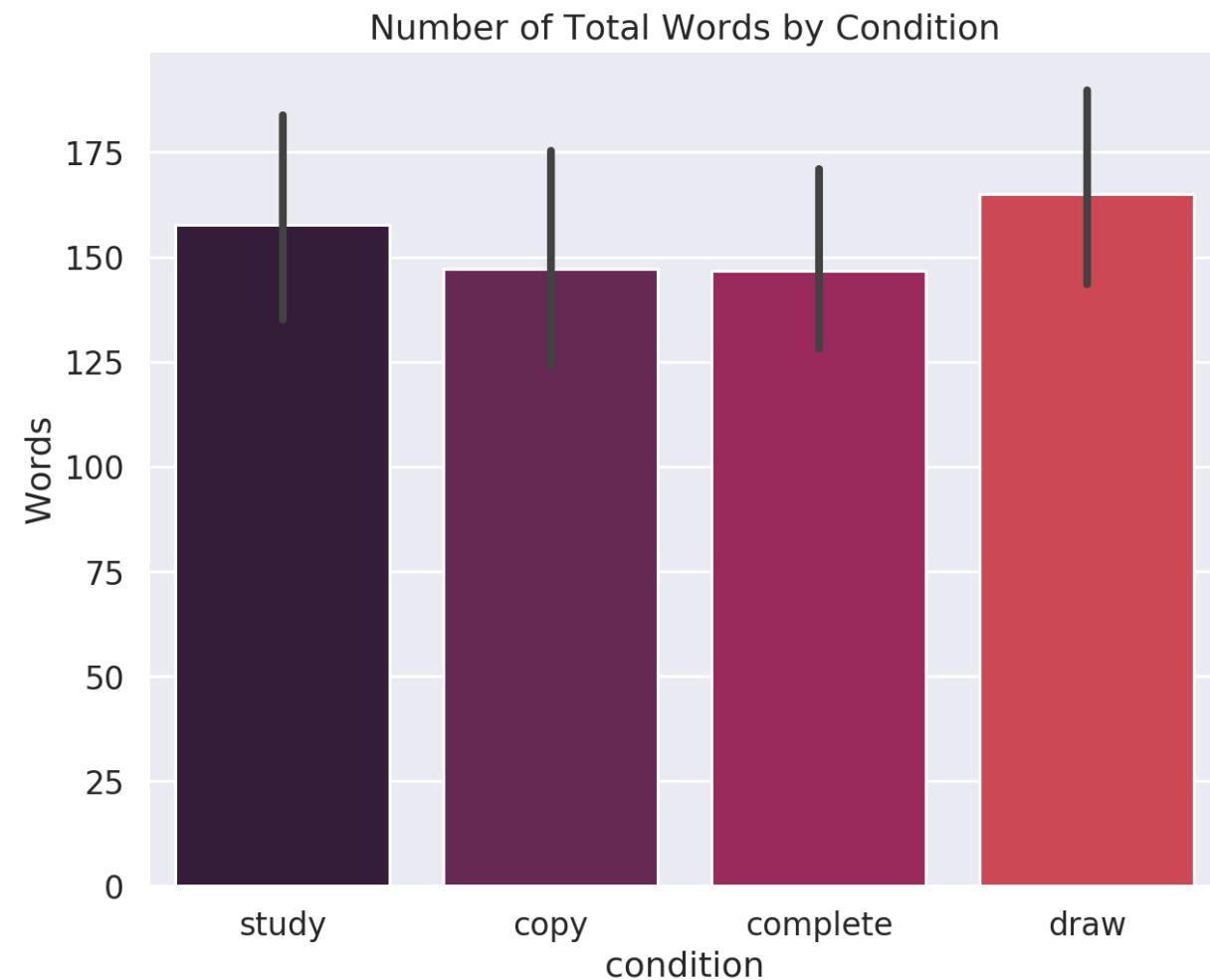
Min: 1 Median: 3.0 Max: 5

Total Words Used on Retention Test



Min: 21

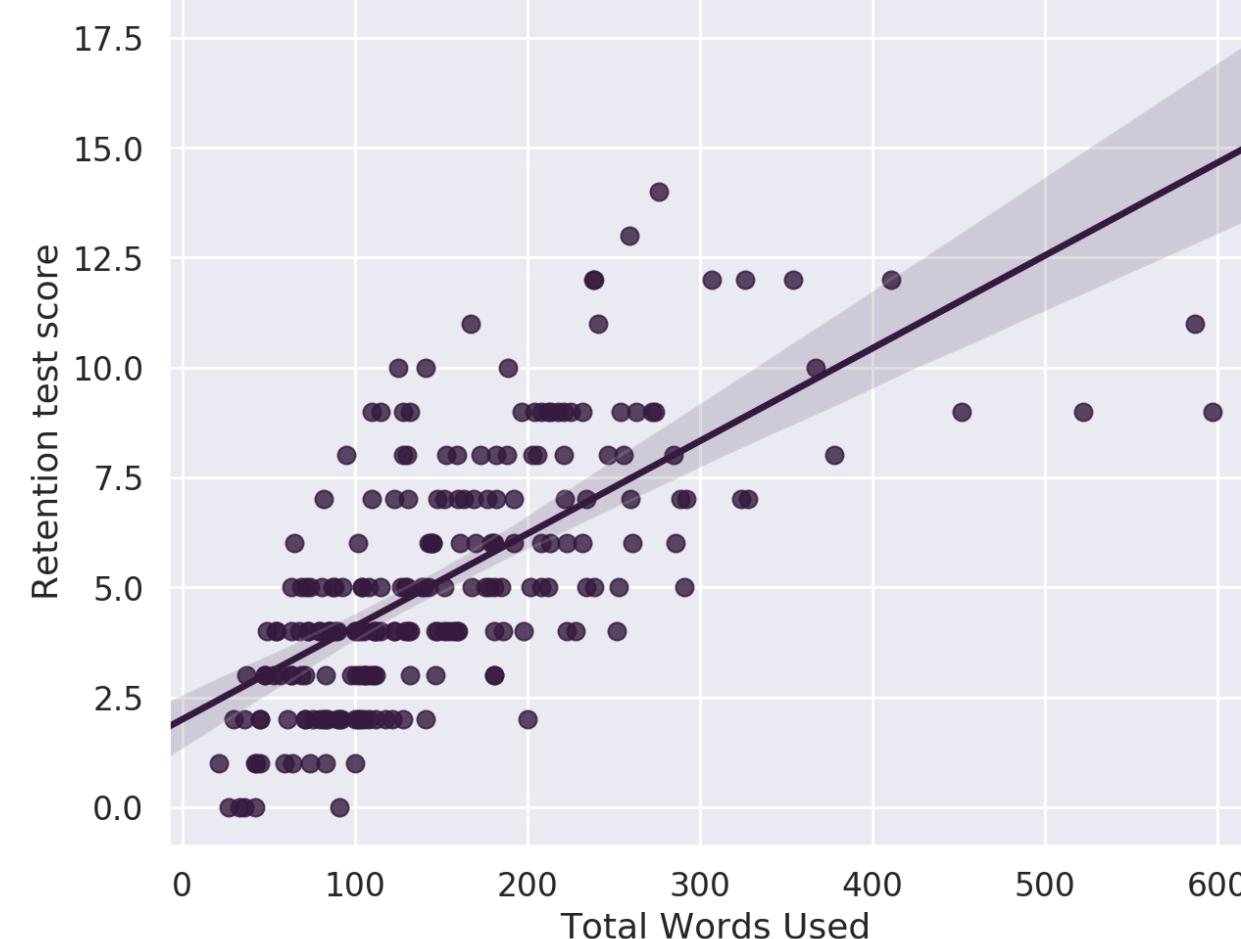
Median: 131.0 Max: 597



$$F(3, 217) = 0.472, p = 0.702$$

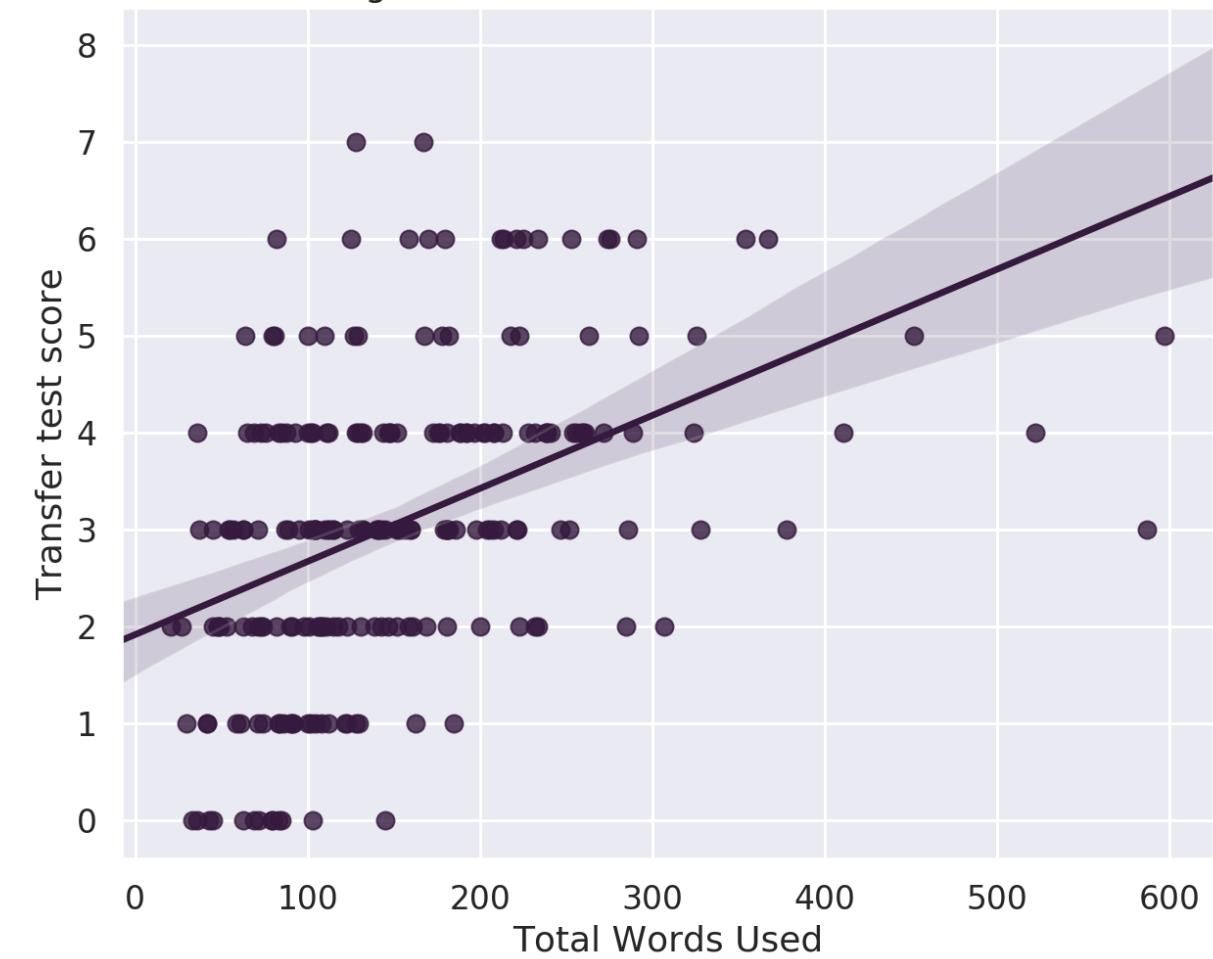
Regressions of Total Words Used

Regression of Total Words and Retention



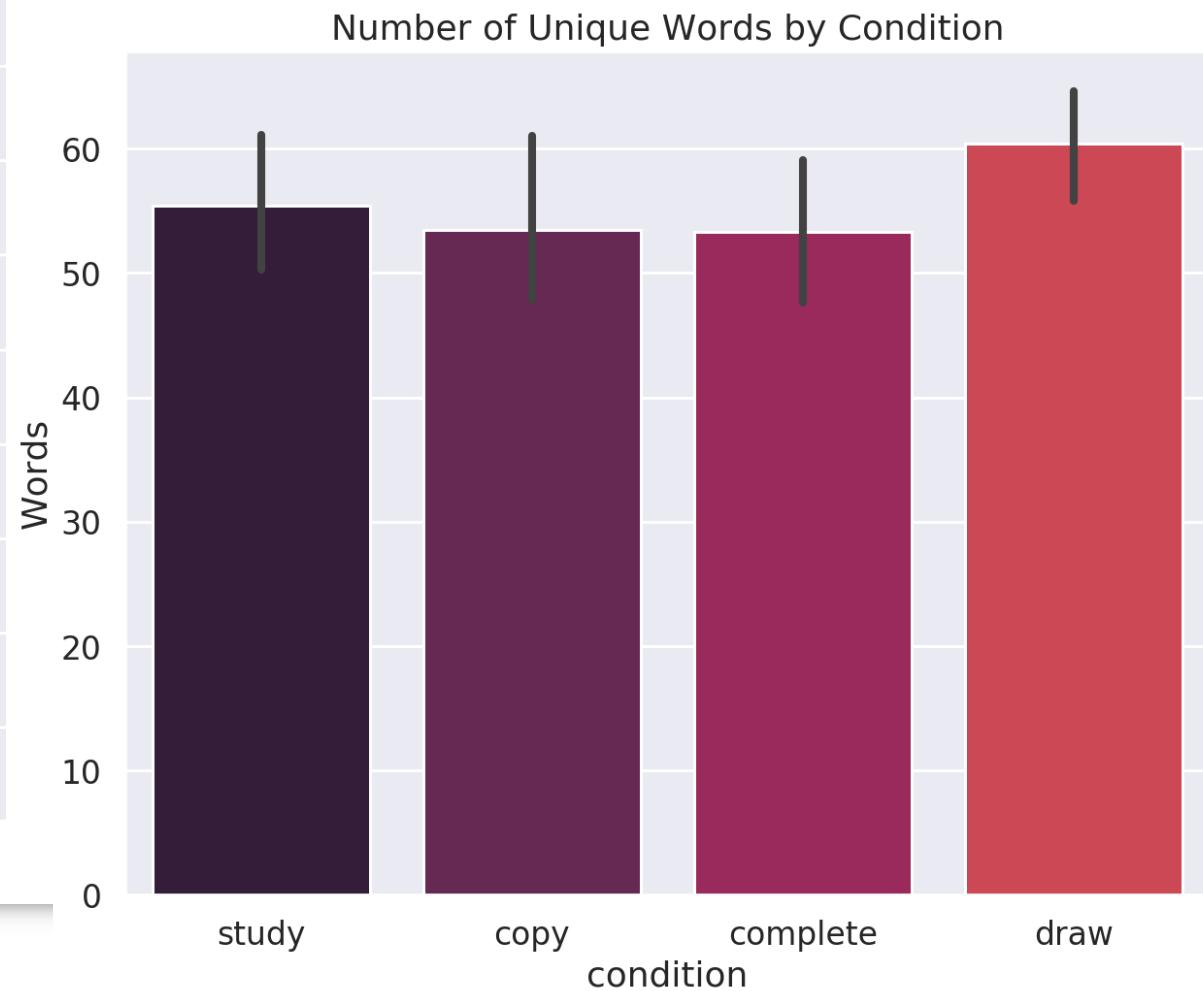
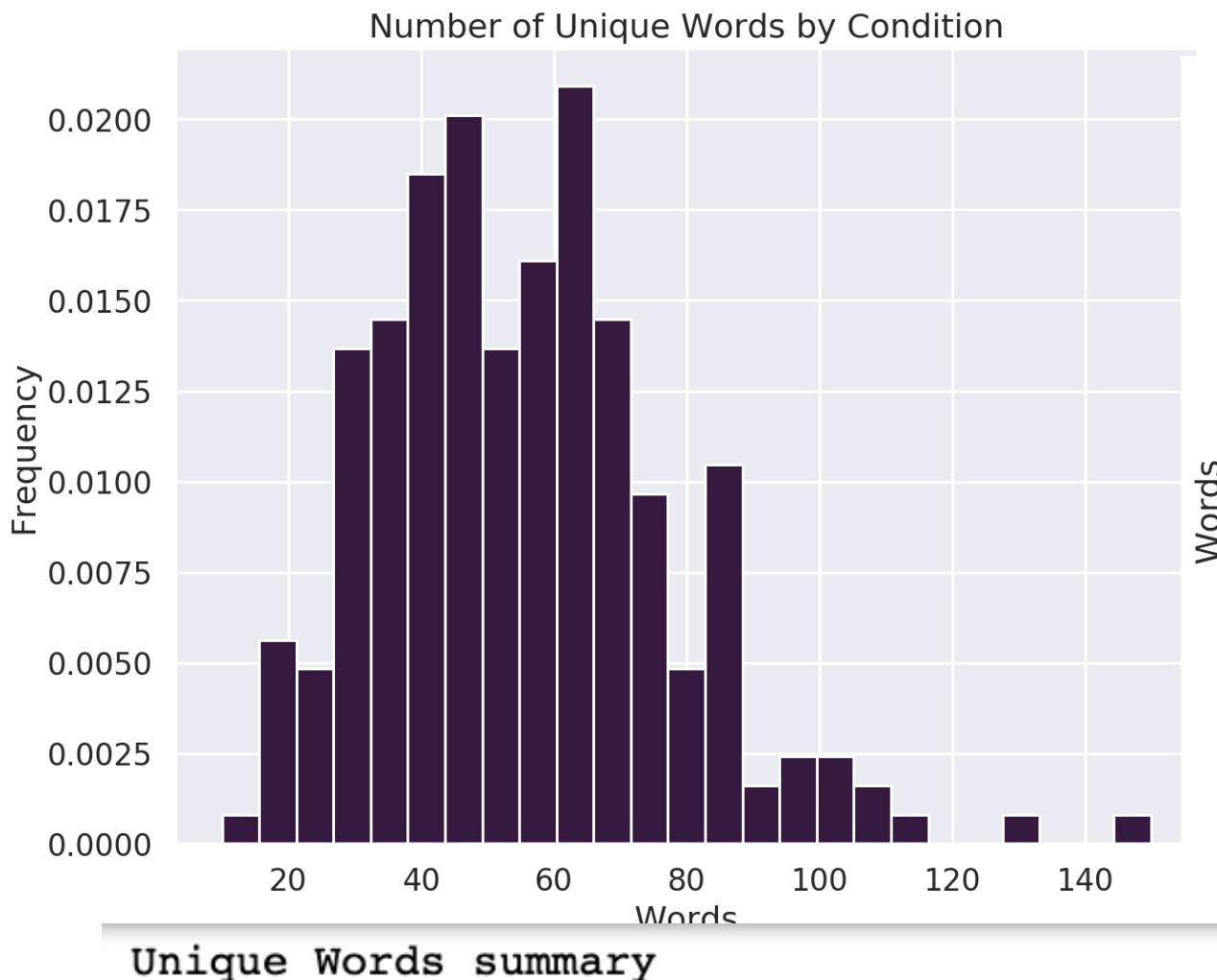
$F(1,219) = 188.72, p < 0.0001, R^2 = 46.29\%$

Regression of Total Words and Transfer



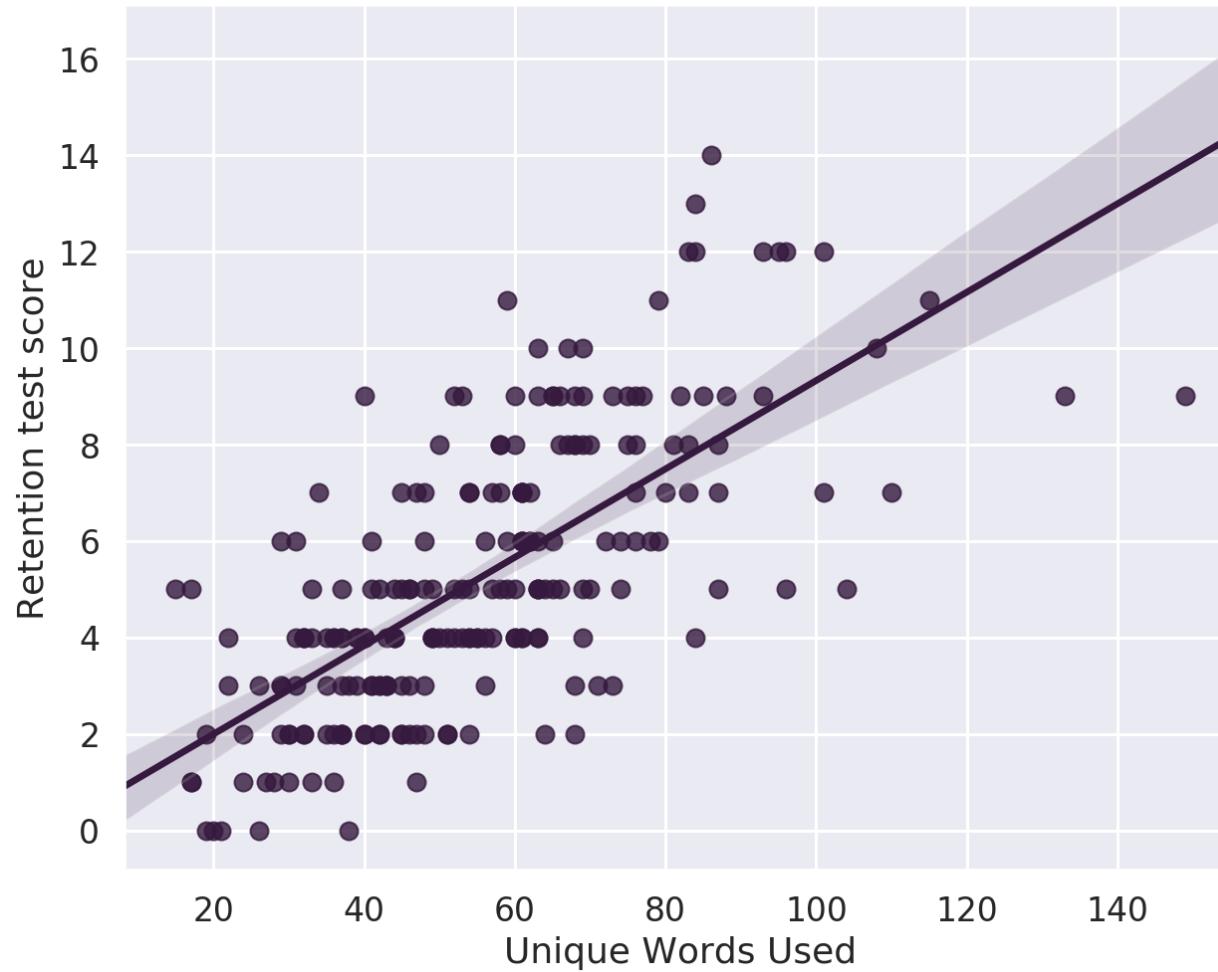
$F(1,219) = 53.31, p < 0.0001, R^2 = 19.58\%$

Total Unique Words Used on Retention Test



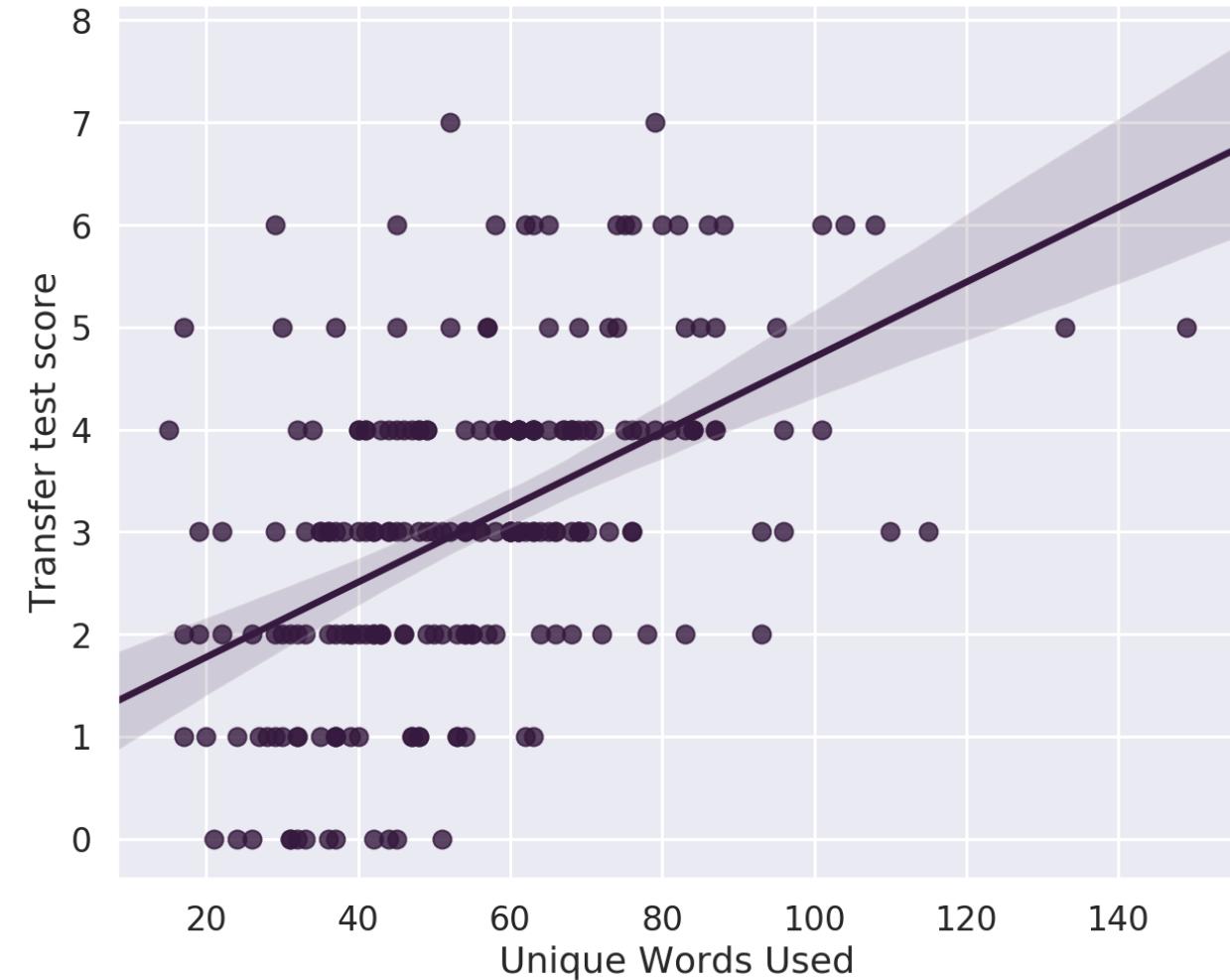
Regressions of Total Unique Words Used

Regression of Unique Words and Retention



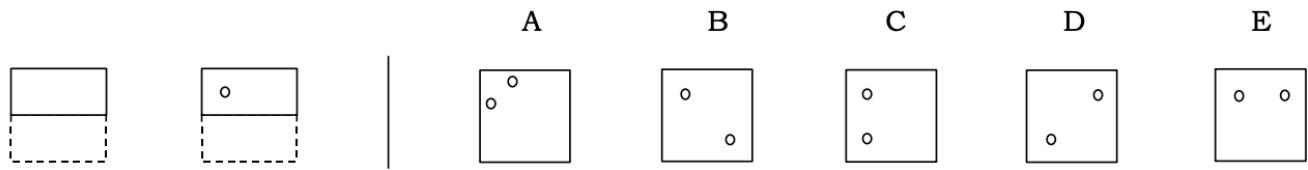
$F(1,219) = 201.36, p < 0.0001$

Regression of Unique Words and Transfer

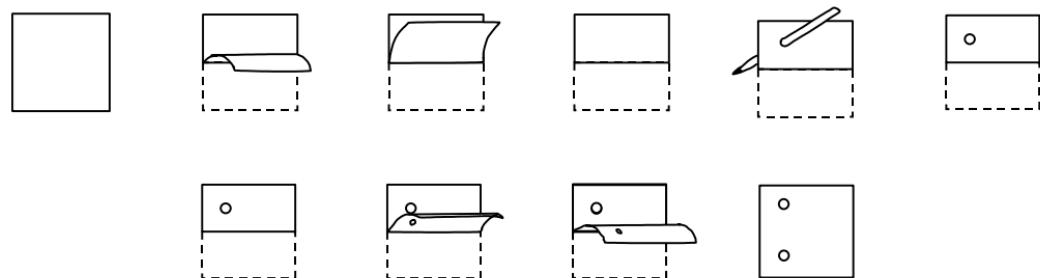


$F(1,219) = 74.51, p < 0.0001, R^2 = 25.05\%$

Seasons Study



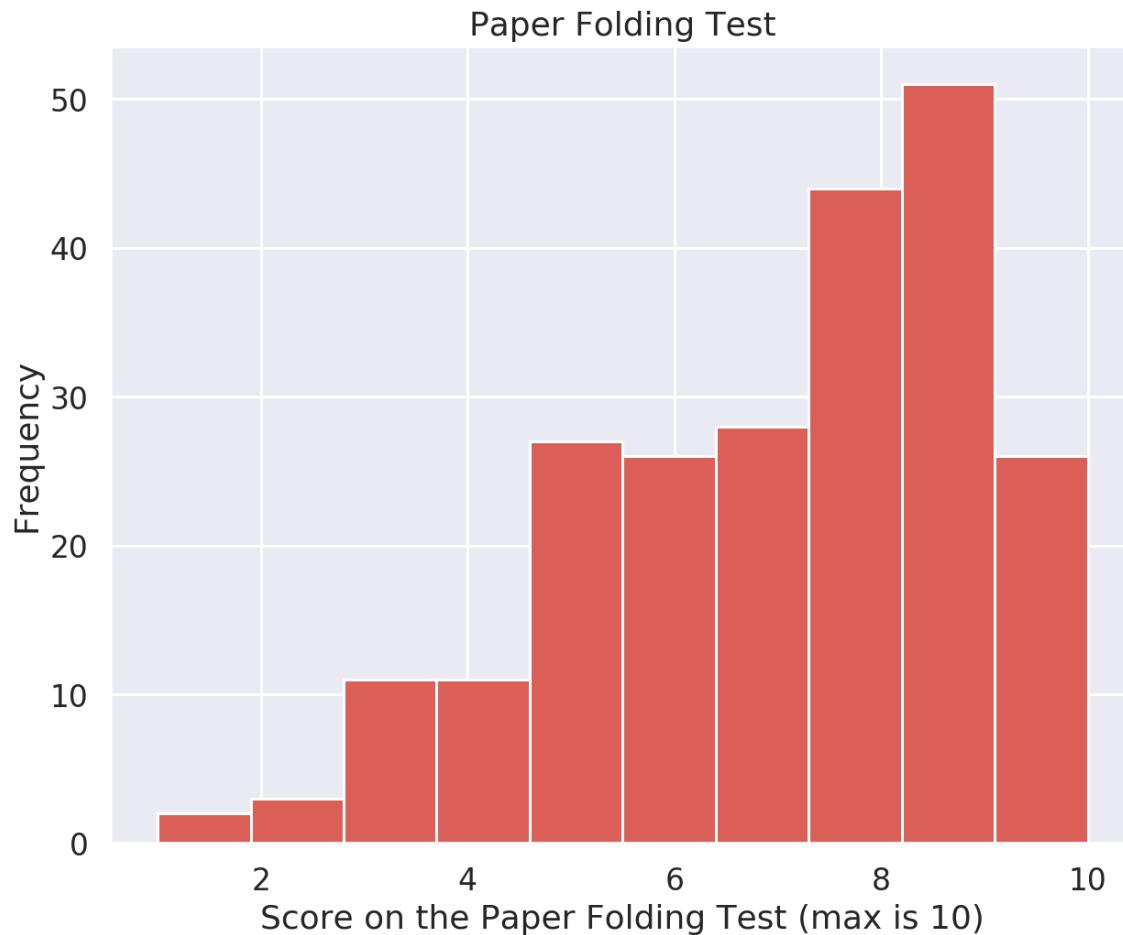
The correct answer to the sample problem above is C and so it should have been marked with an X.
 The figures below show how the paper was folded and why C is the correct answer.



Measuring Individual Differences

- ❖ Perceptual ability
- ❖ Prior knowledge

Perceptual Ability



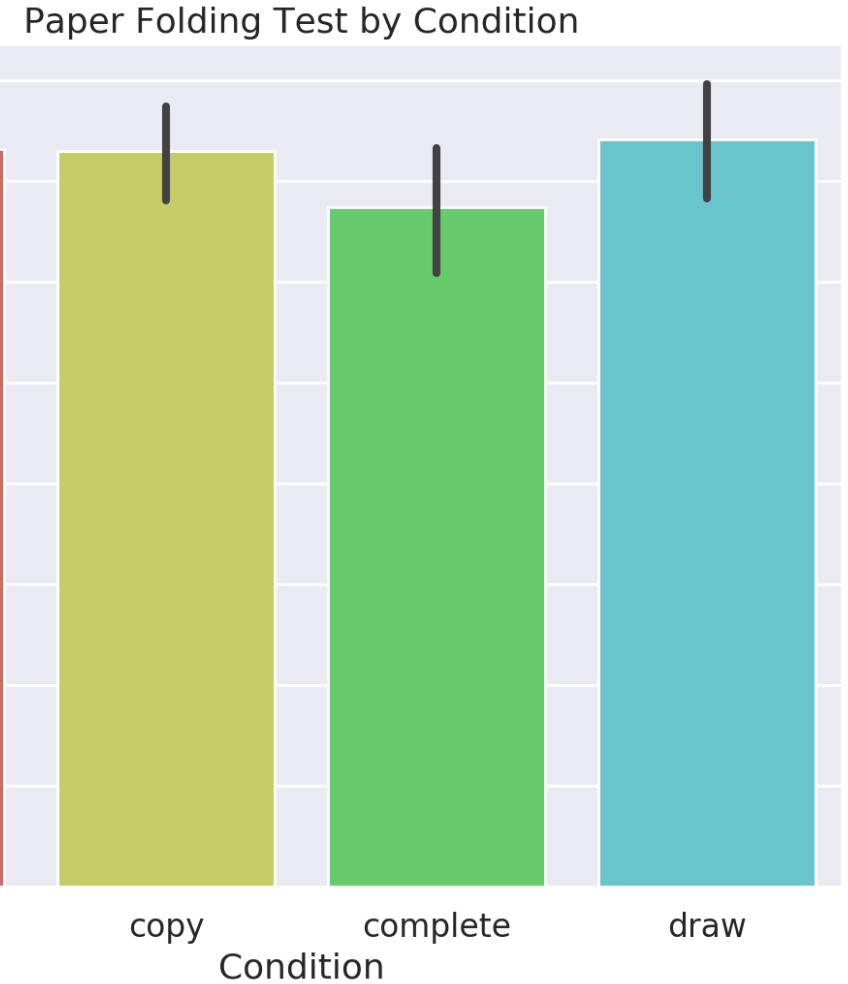
Paper Folding Test

Mean: 7.175

Standard dev: 2.126

Min: 1 Median: 8.0

Max: 10

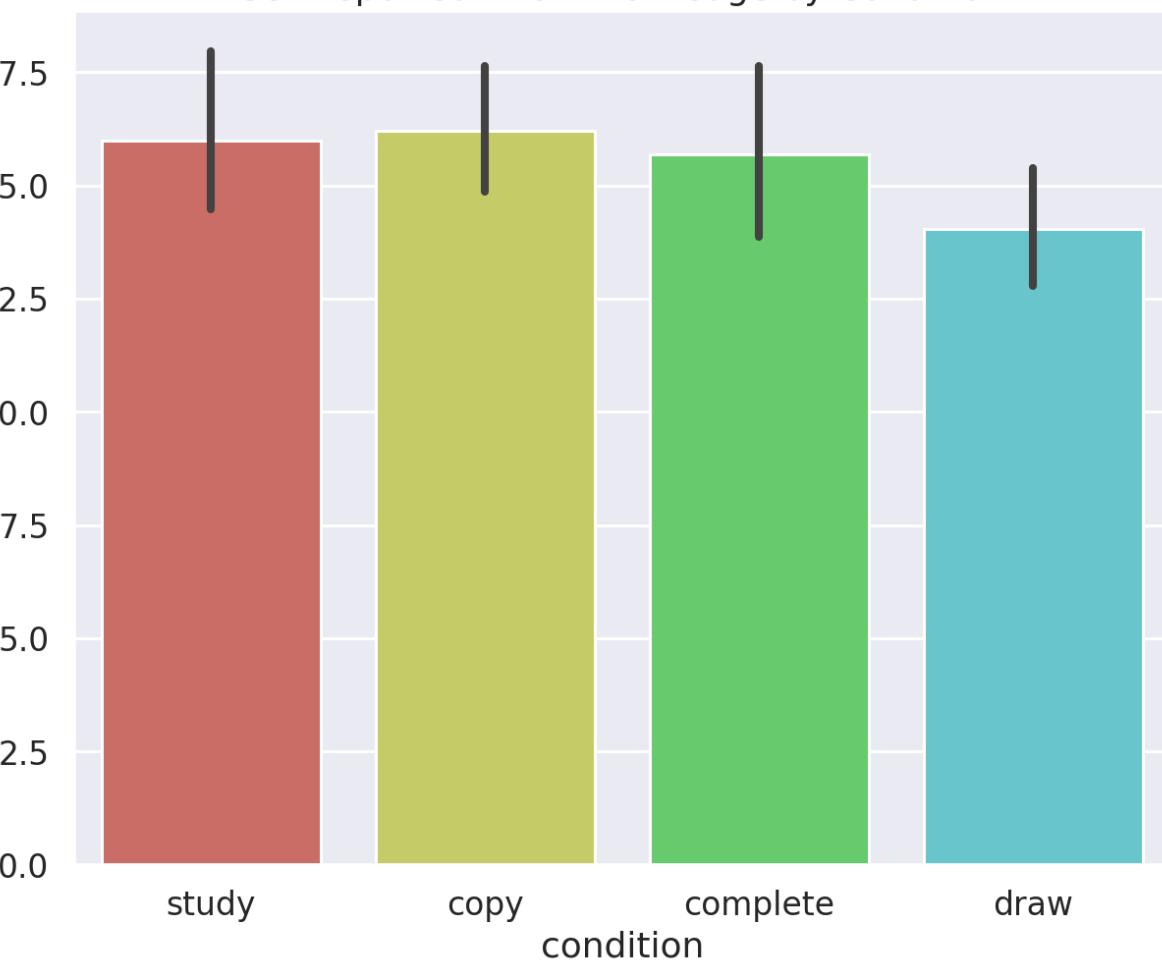


$$F(3, 225) = 1.204, p=0.309$$

Prior Knowledge



Self-reported Prior Knowledge by Condition



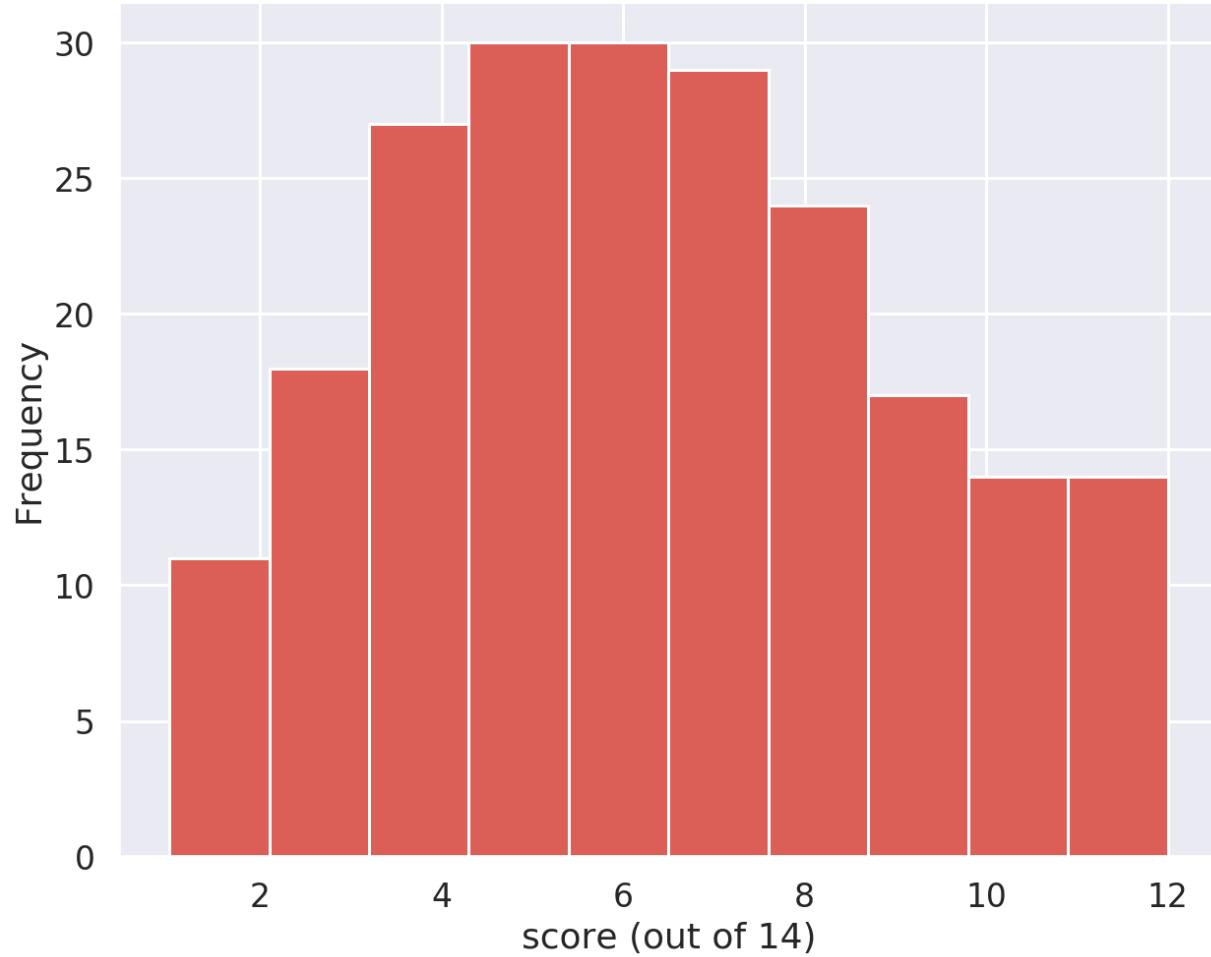
Self-reported Prior Knowledge

Mean: 15.576 Standard dev: 6.424

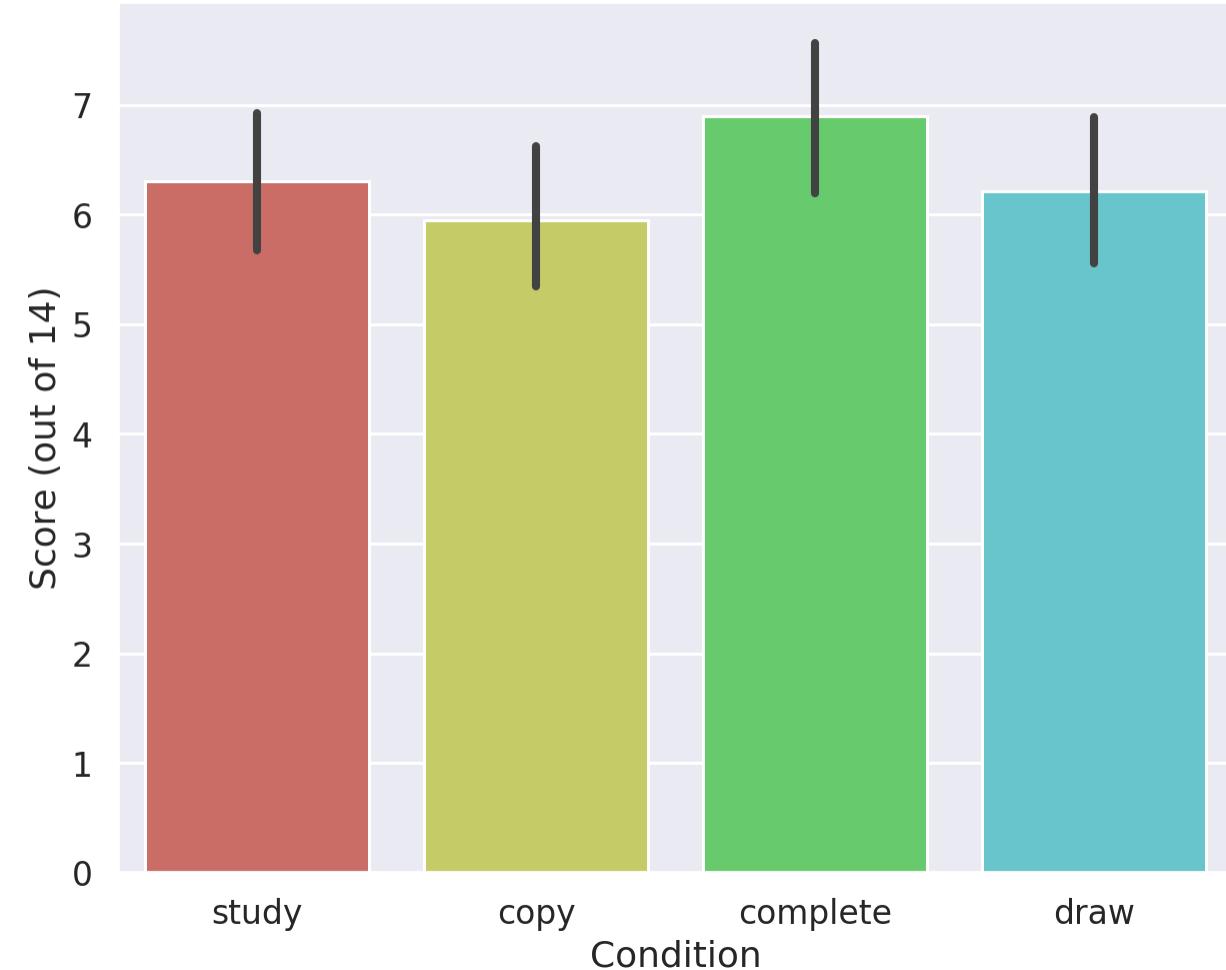
Min: 8 Median: 16.0 Max: 50

Pre-test Performance

Histogram of Pre-test score



Performance on the MC Pre-Test by Condition



Multiple choice pretest Score Summary

Mean: 6.346

Standard_dev: 2.568

Min: 1.0

Median: 6.0

Max: 12.0

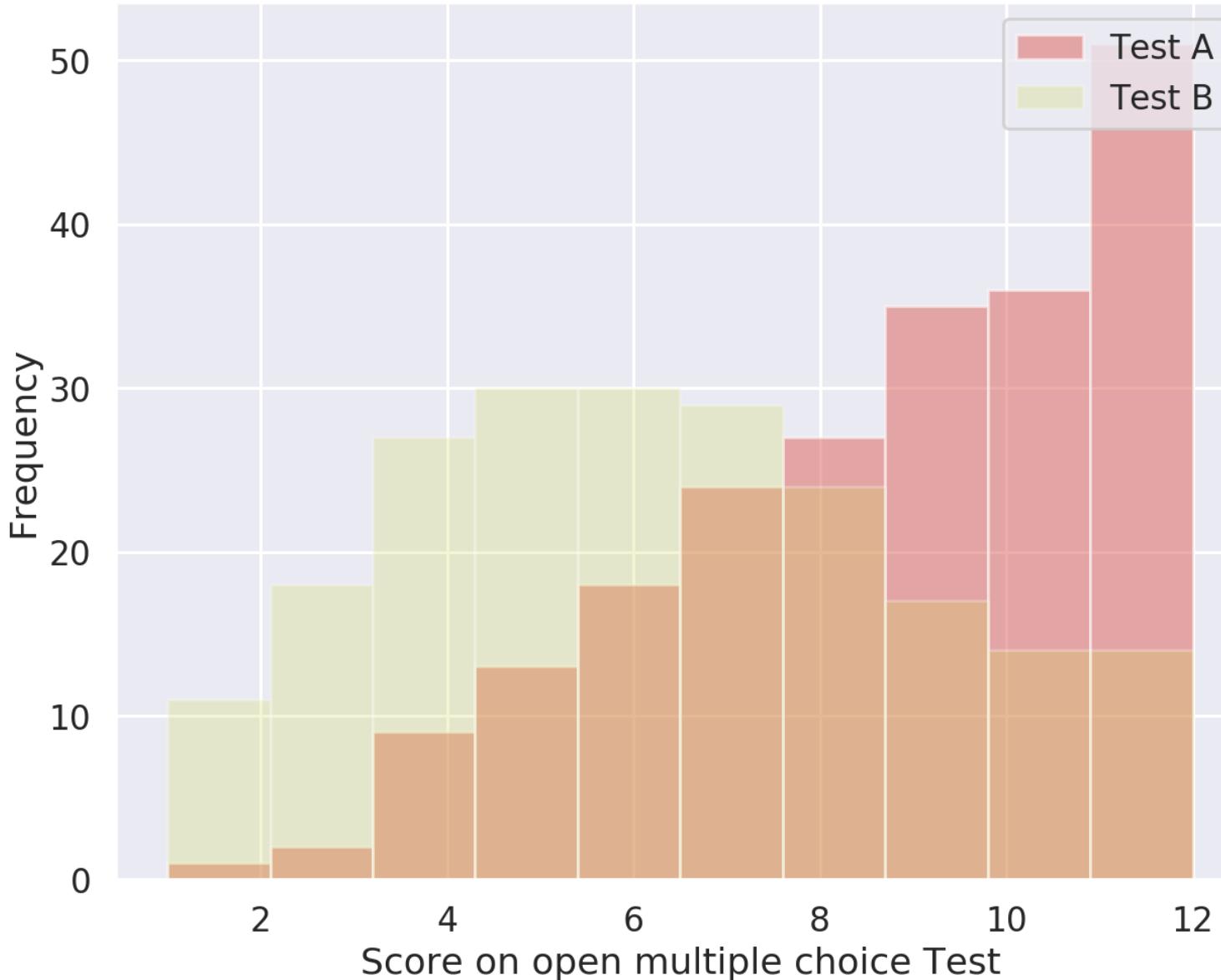
Multiple Choice Performance

28 multiple choice questions

14 pre, 14 post-test

Test A vs Test B Performance

MC Test Version Performance



Test A Total Score

Mean: 8.588 standard dev: 2.315

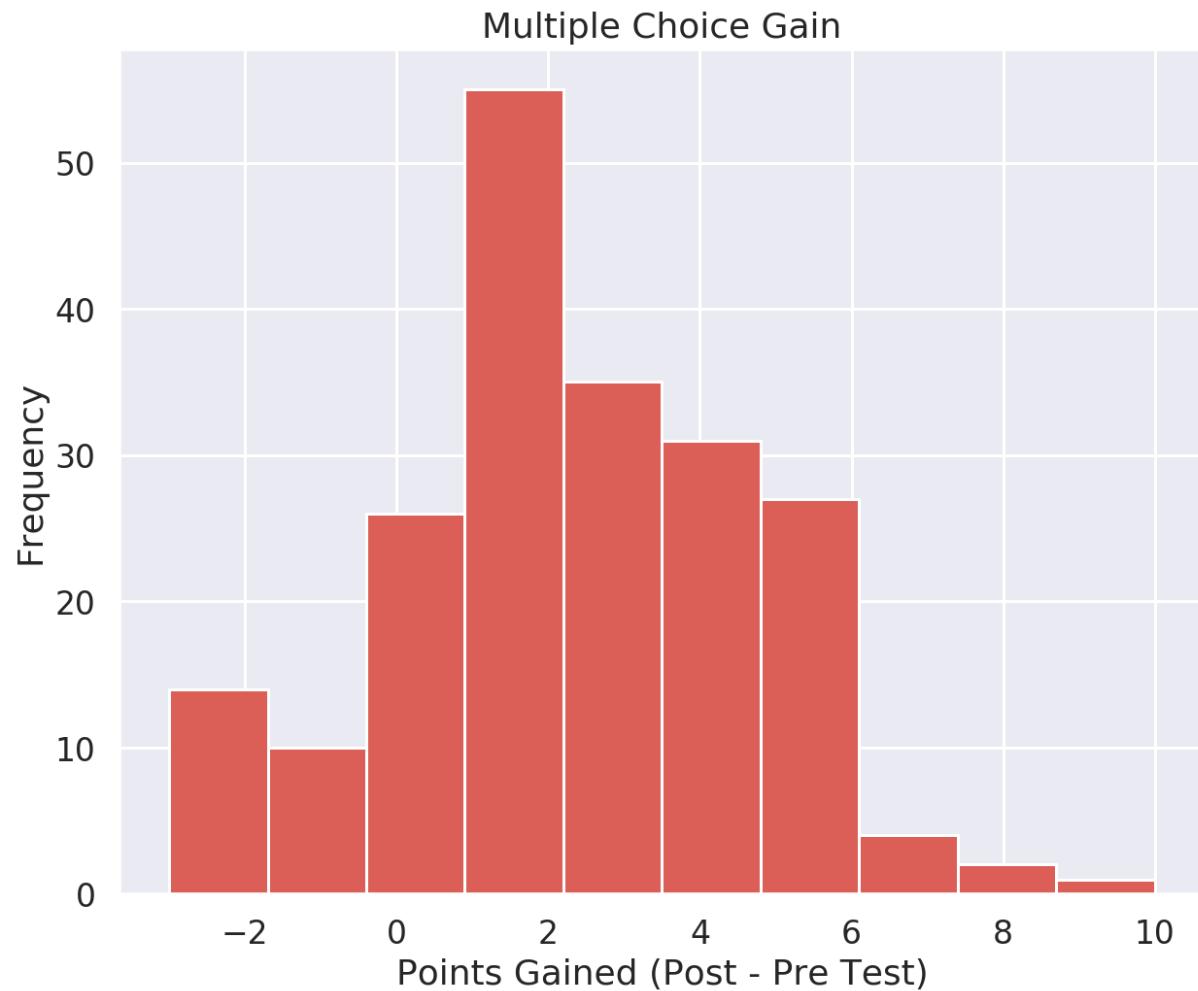
Min: 1.0 Median: 9.0 Max: 12.0

Test B Total Score

Mean: 6.346 standard dev: 2.568

Min: 1.0 Median: 6.0 Max: 12.0

Multiple Choice Gain



Multiple choice gain

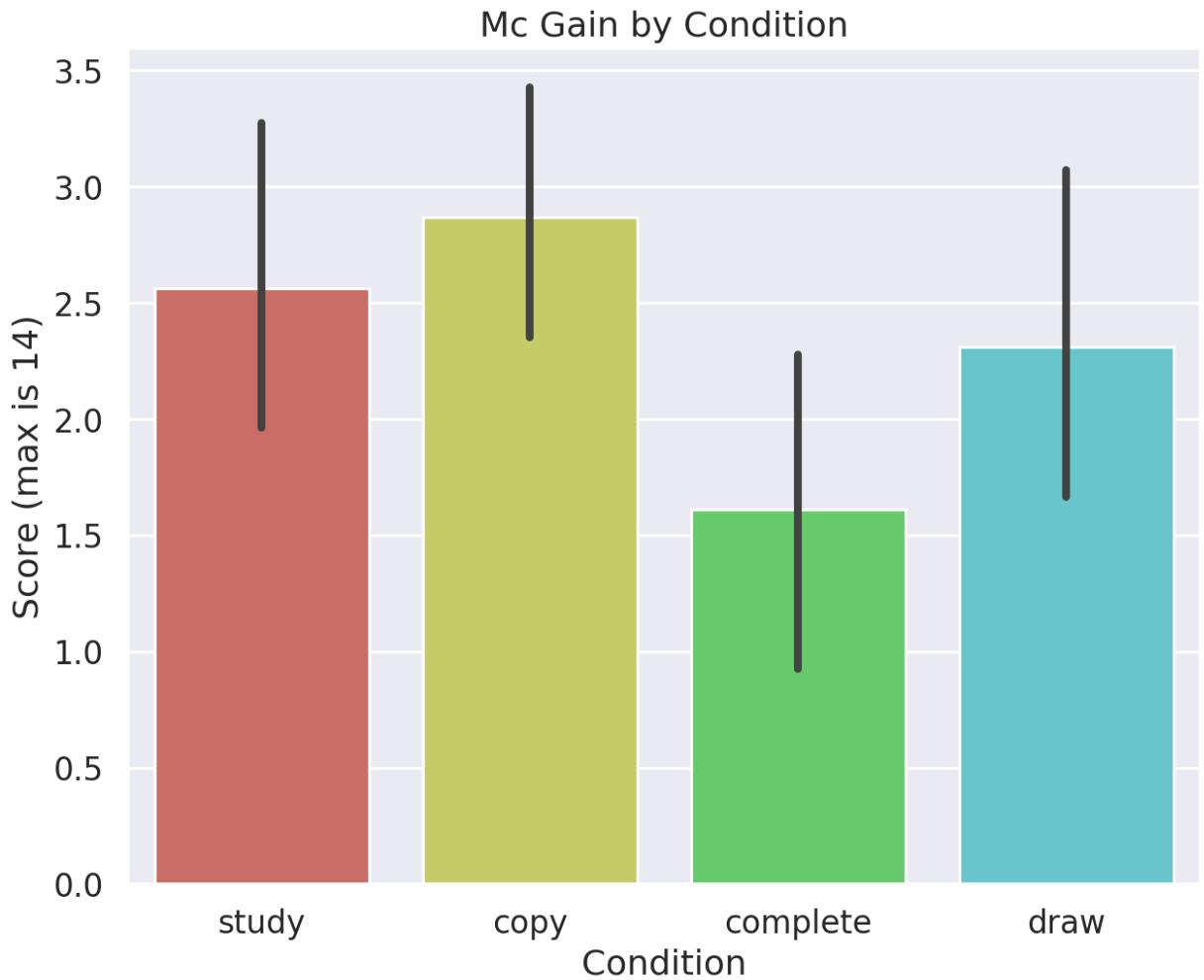
Mean: 2.341

Standard_dev: 2.436

Min: -3.0

Median: 2.0

Max: 10.0



$$F(3, 225) = 2.688, \quad p=0.0476$$

Measuring Cognitive Load

Intrinsic

“The topic/topics covered in the activity was/were very complex.”

Extraneous

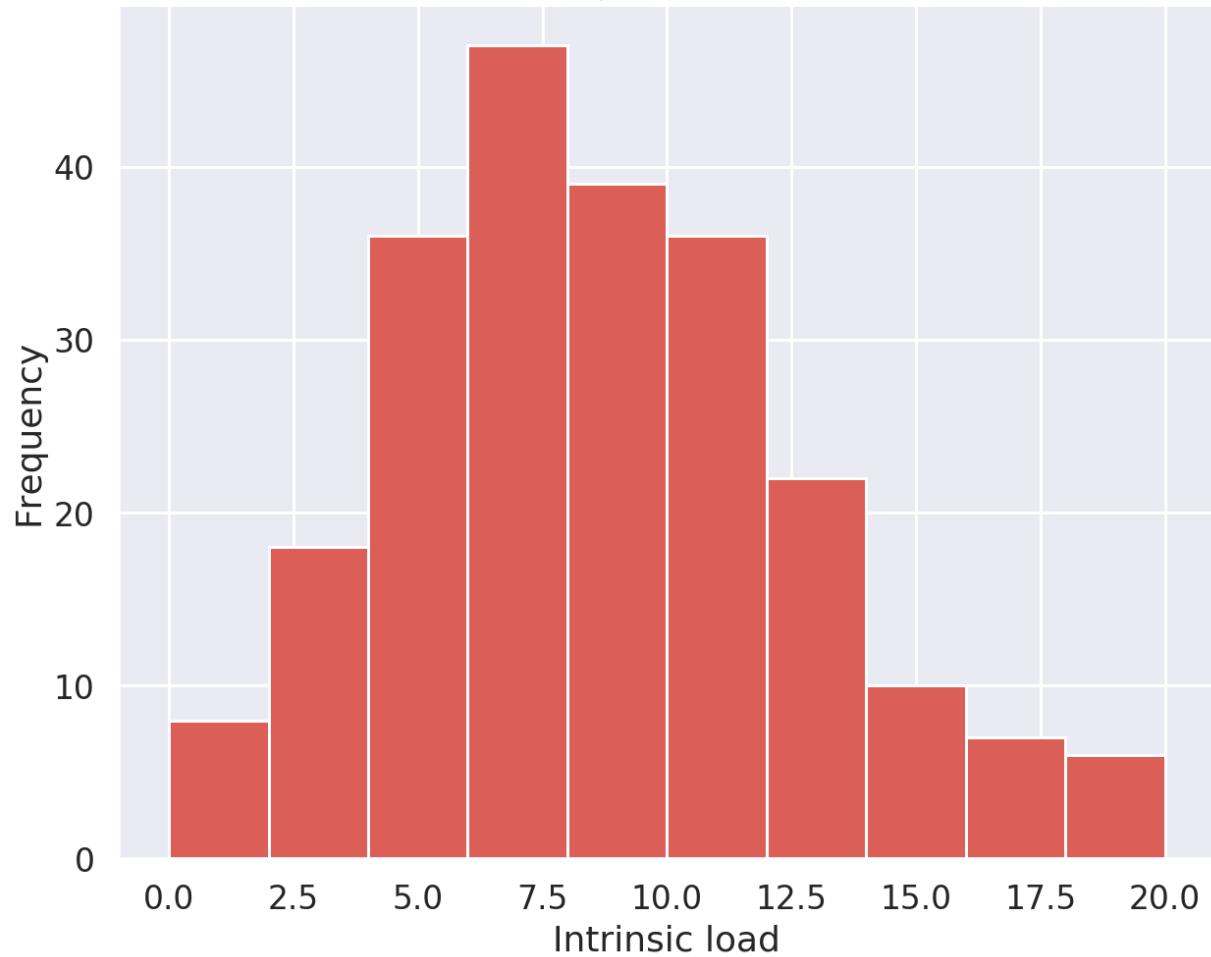
“The instructions and/or explanations during the activity were very unclear.”

Germane

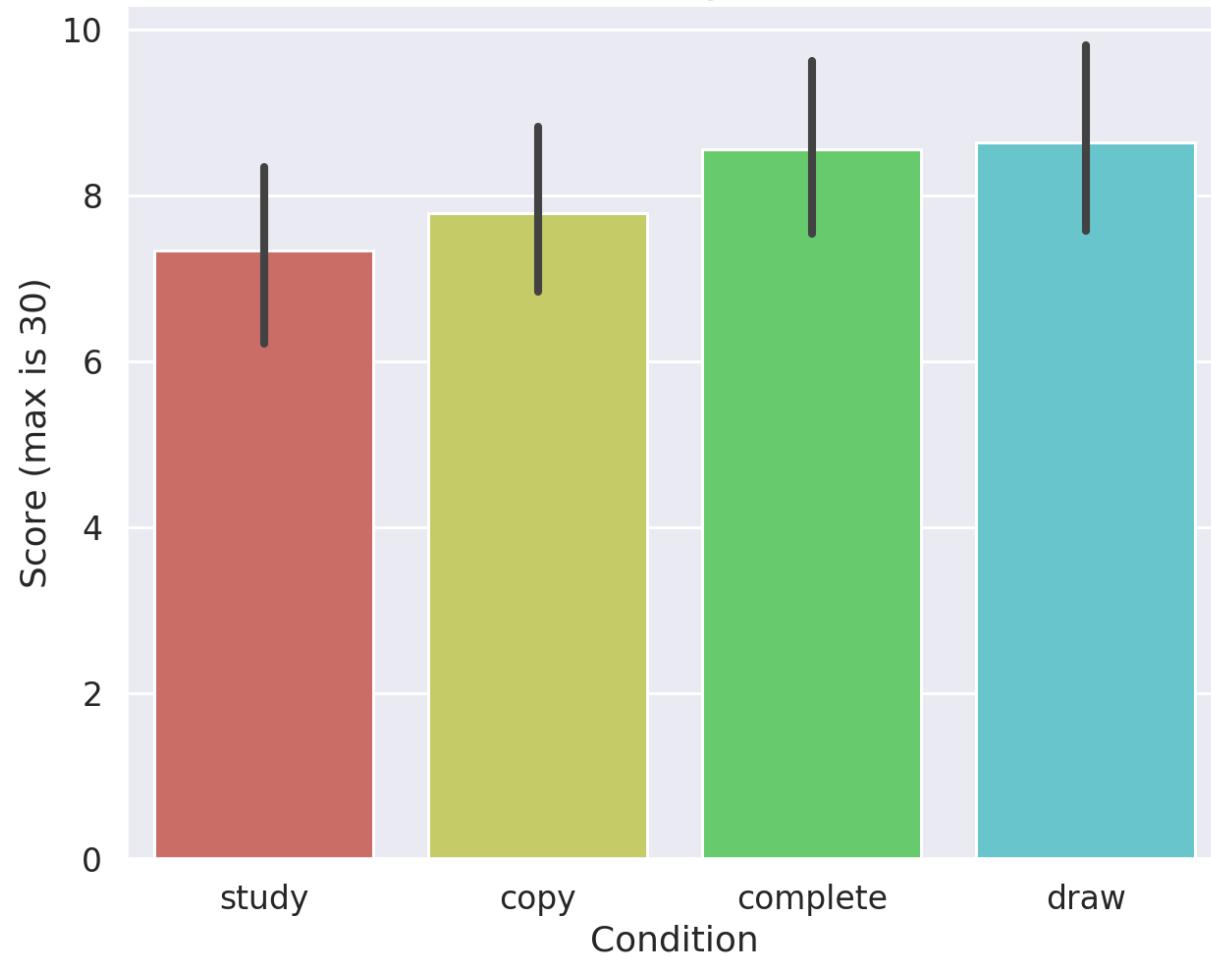
“The activity really enhanced my understanding of the topic(s) covered.”

Total Intrinsic Load (3 items)

Total Self-Reported Intrinsic Load



Intrinsic load by Condition



Intrinsic Load

Mean: 8.039

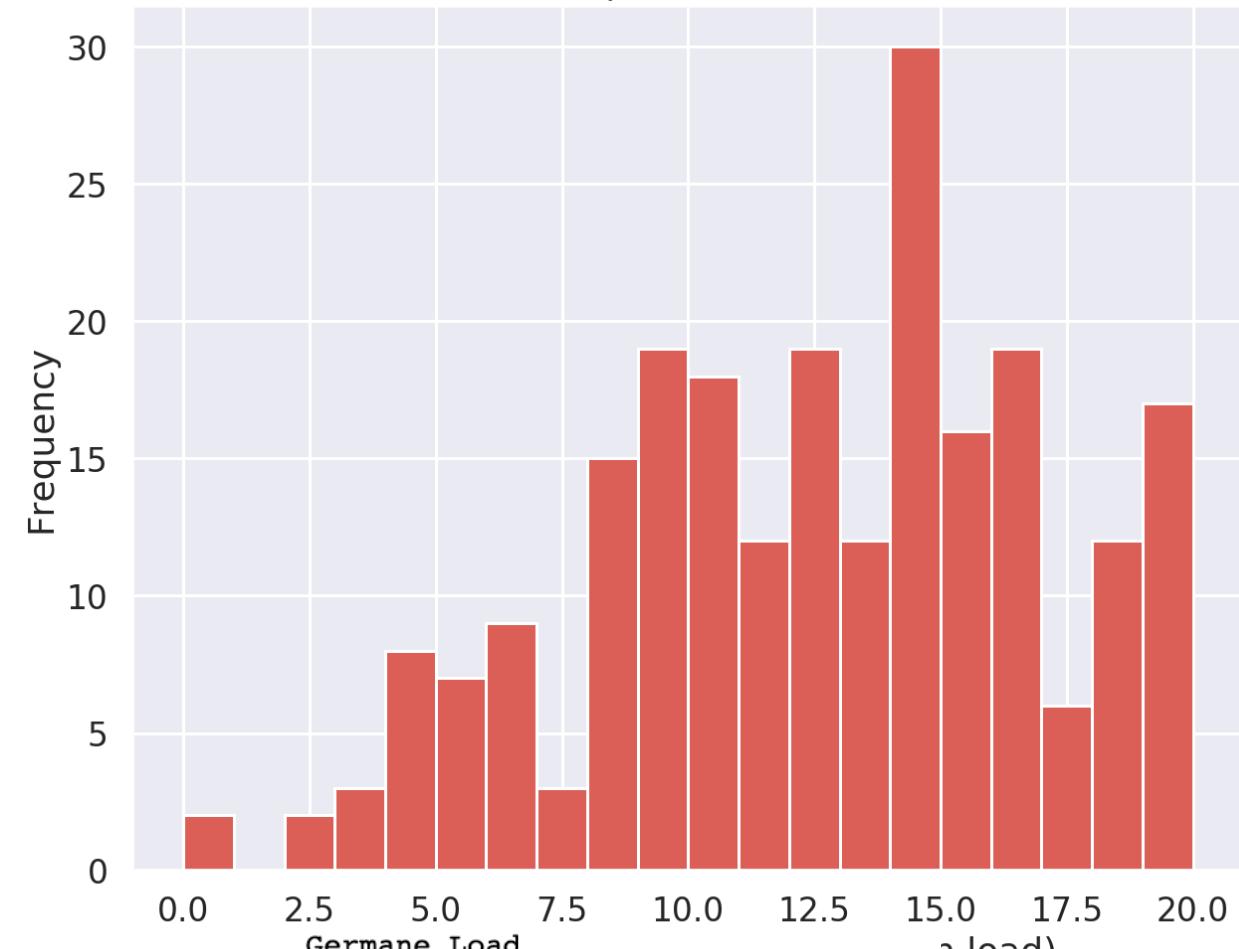
Standard_dev: 4.118

Min: 0 Median: 8.0

Max: 20

Total Germane Load (4 items)

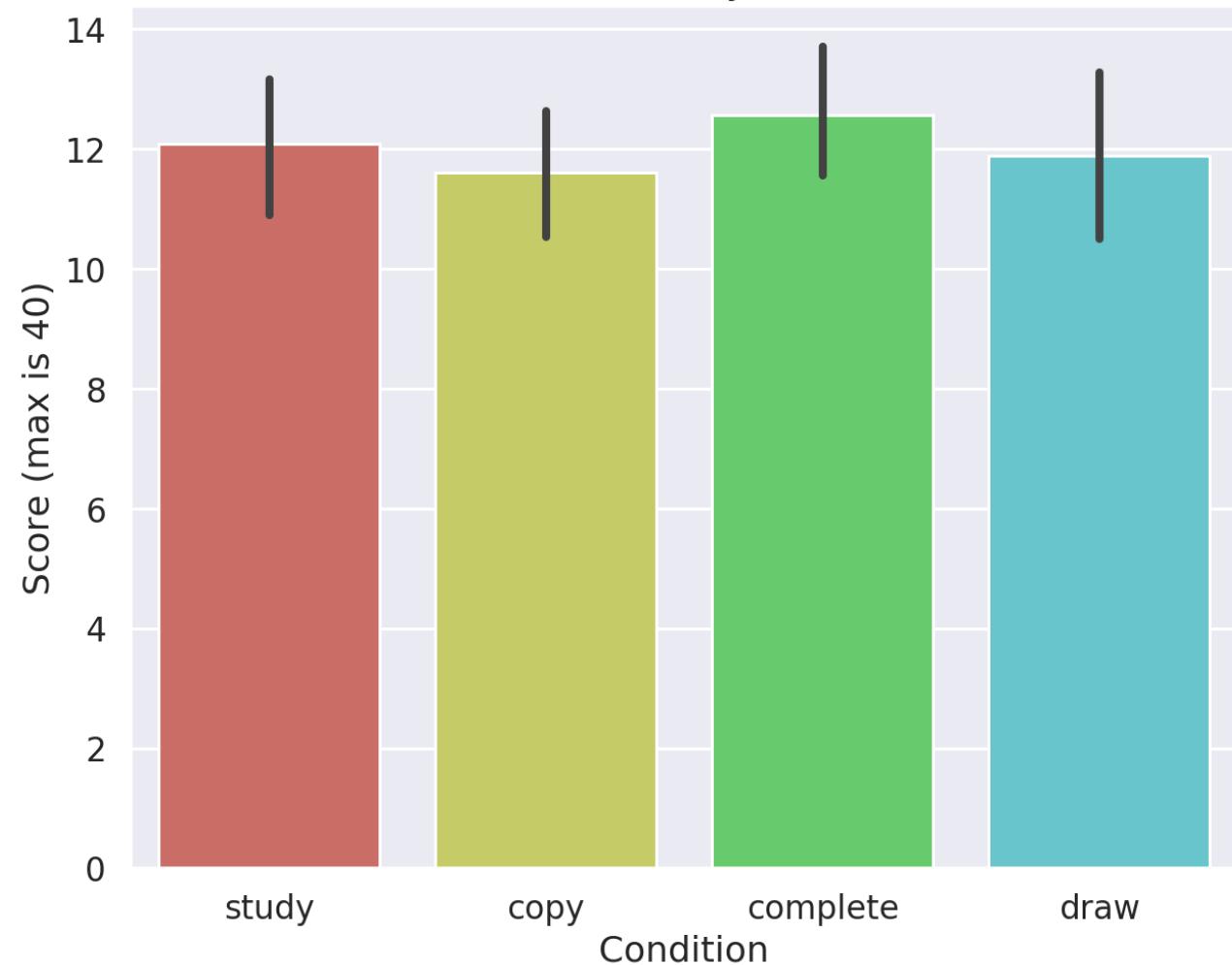
Total Self-Reported Germane Load



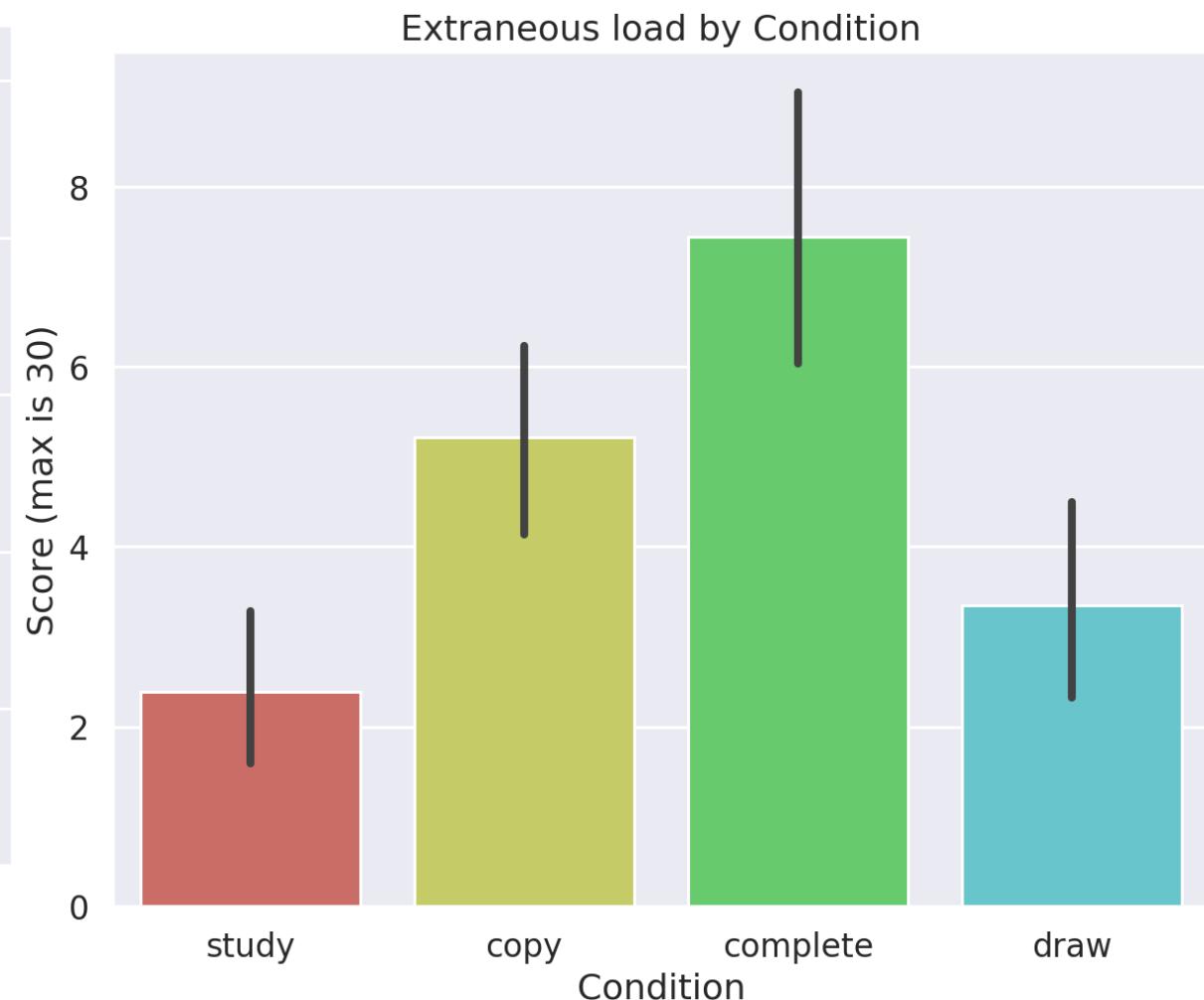
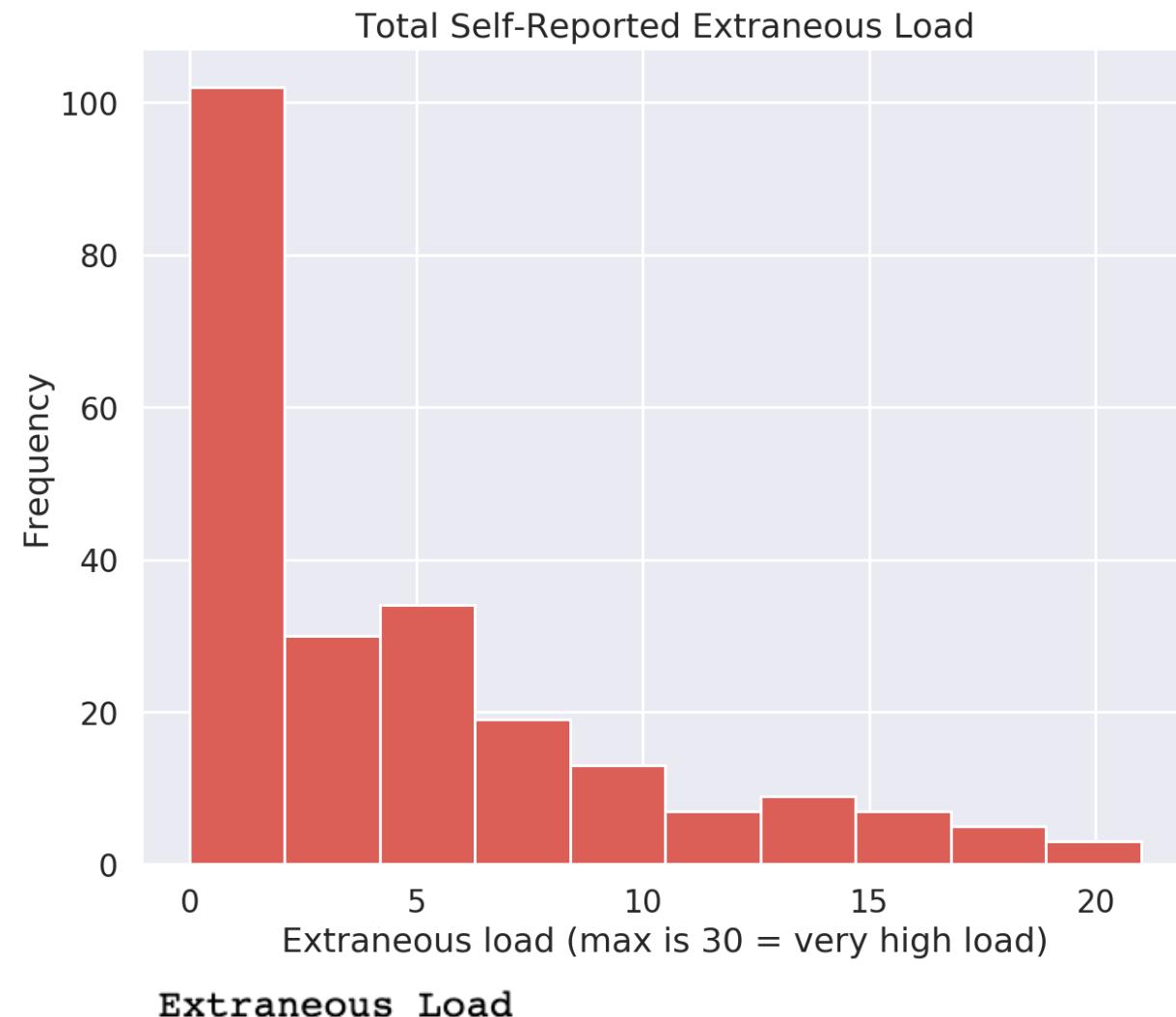
Mean: 12.048 Standard dev: 4.518

Min: 0 Median: 12.0 Max: 20

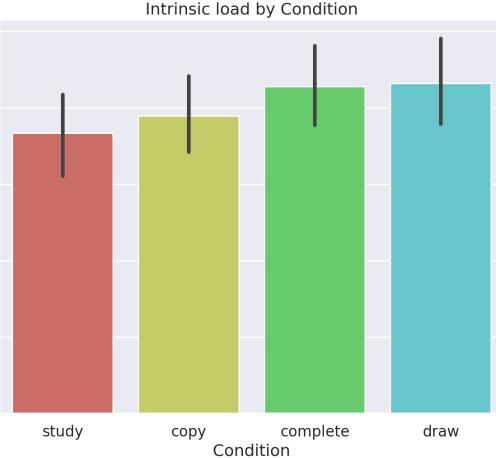
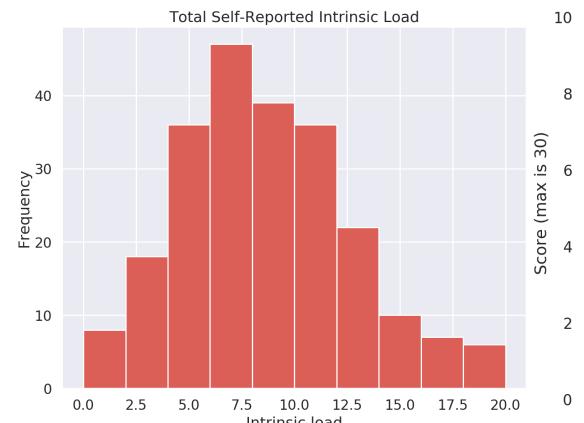
Germane load by Condition



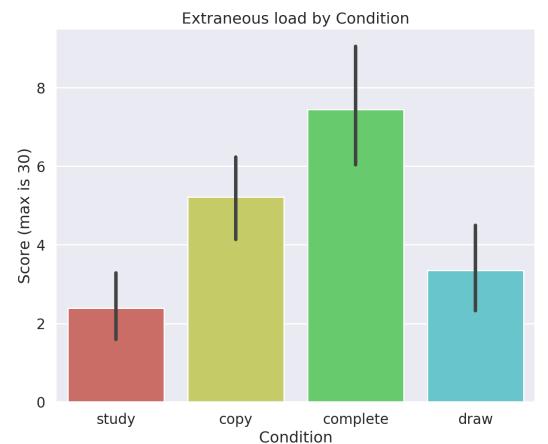
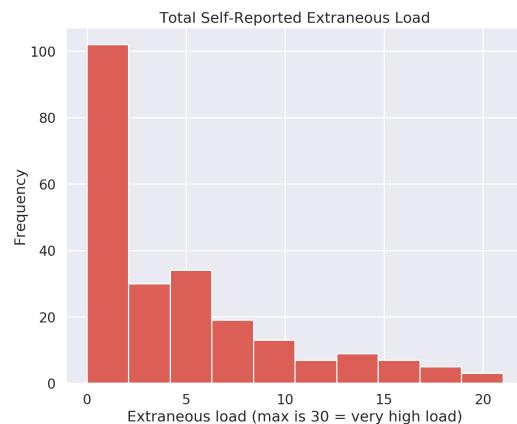
Total Extraneous Load (3 items)



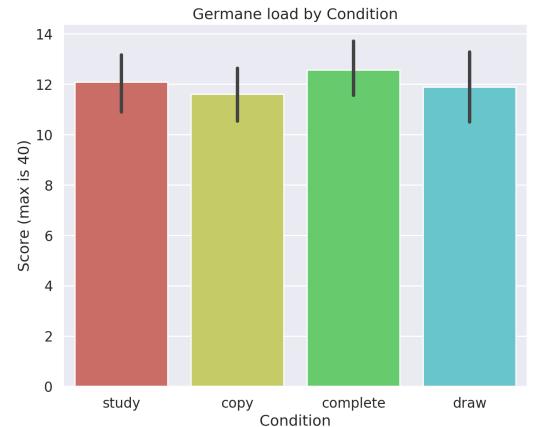
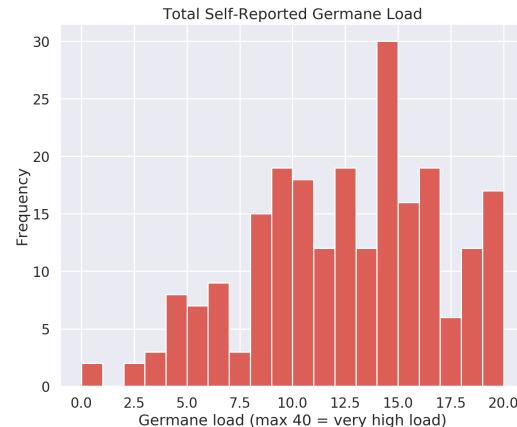
IL



EL



GL



Please rate how much you enjoyed the drawing task.

- Liked a great deal
- Liked some
- Neither
- Dislike
- Dislike

```
## Unique and Total Word Calculator
size = len(values) # gives the number of rows(i.e., cells in this case) which is 238
n=1 # we want to start from cell 0, the first increment would make the -1 a 0
lst_words = []
lst_2_words = []
while True:
    n += 1
    if n == size:
        break
    # inspect the next cell
    print ("-" * 35, "cell" + str(n), "-" * 35)
    text = values[n][0]
    text_str = str(text).lower()
    no_punct_str = remove_punctuation(text_str)

    d = {} # initialize an empty dictionary
    for word in no_punct_str.split():
        try:
            d[word] += 1 # the entry exists
        except KeyError:
            d[word] = 1. # a new entry

    uqs = [] # will hold the list of unique words for each cell
    for k in d.keys():
        if d[k] == 1:
            uqs.append(k)
    lst_words.append(len(uqs)) # append the number of unique words

    d2 = {} # initialize an empty dictionary
    wrds = [] #will hold the list of total words for each cell
    for word in no_punct_str.split():
        wrds.append(word)
    lst_2_words.append(len(wrds))
    # I am just printing the list of unique words.

    print ("The text in this cell:\n", text, "\n")
    print("The number of words in this cell:\n",len(wrds),'\n\n')
    print("unique words in this cell:\n",uqs, "\n\n")
    print("The number of unique words in this cell:\n", len(uqs), '\n\n')
```

A black hole is an indefinite space. It is named black because no light can escape a hole because it is seen as a hole through a telescope. Its center is made up of neutrons.Two stars collapseThe black is made up of a center (a ball of neutrons), a Schwarzschild radius that helps approximate the size of the black hole and an external horizon which separates the inside of the black hole with the outside of space.singularity is the enlargement of a center because it is infinite in time

The number of words in this cell:
89

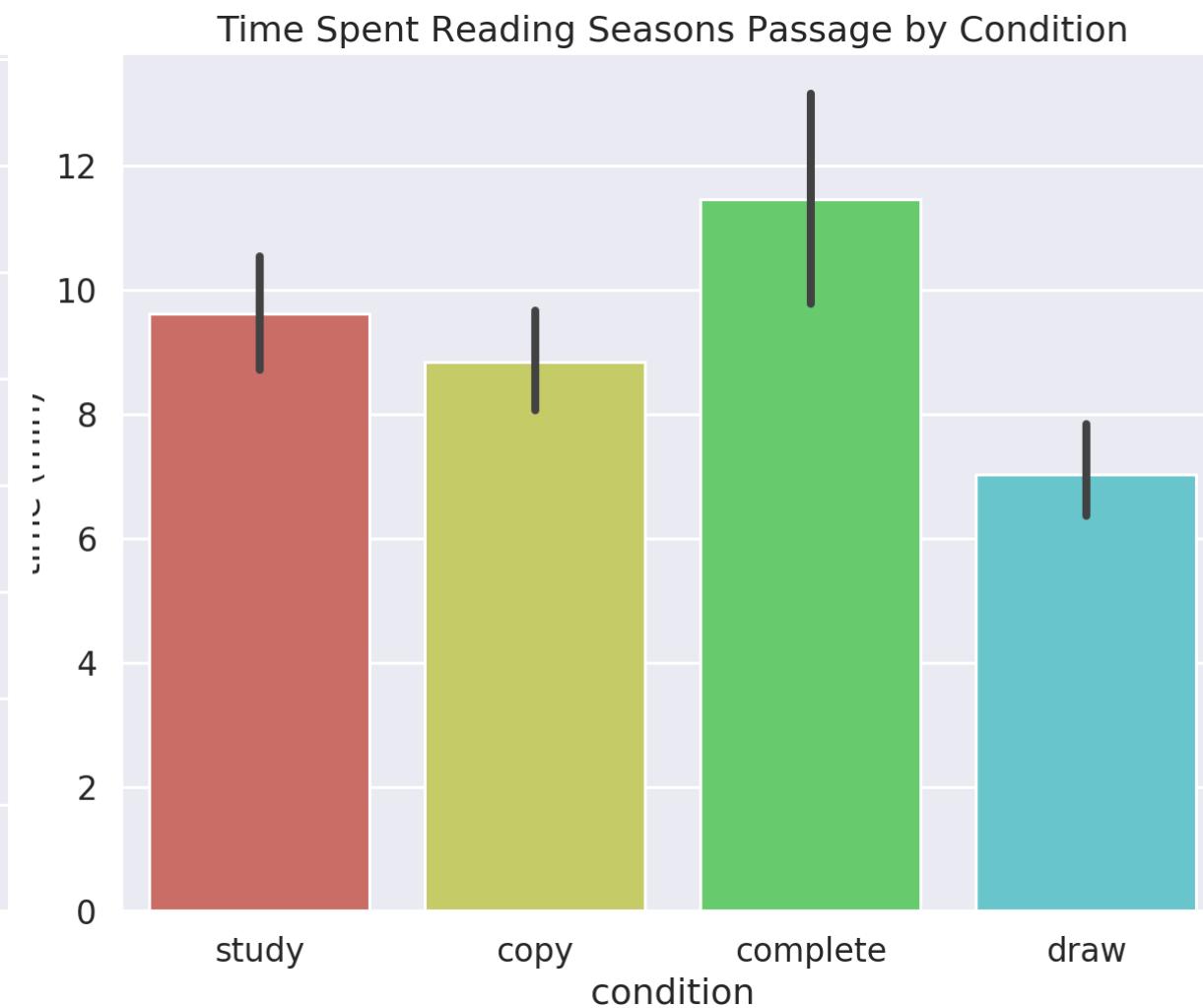
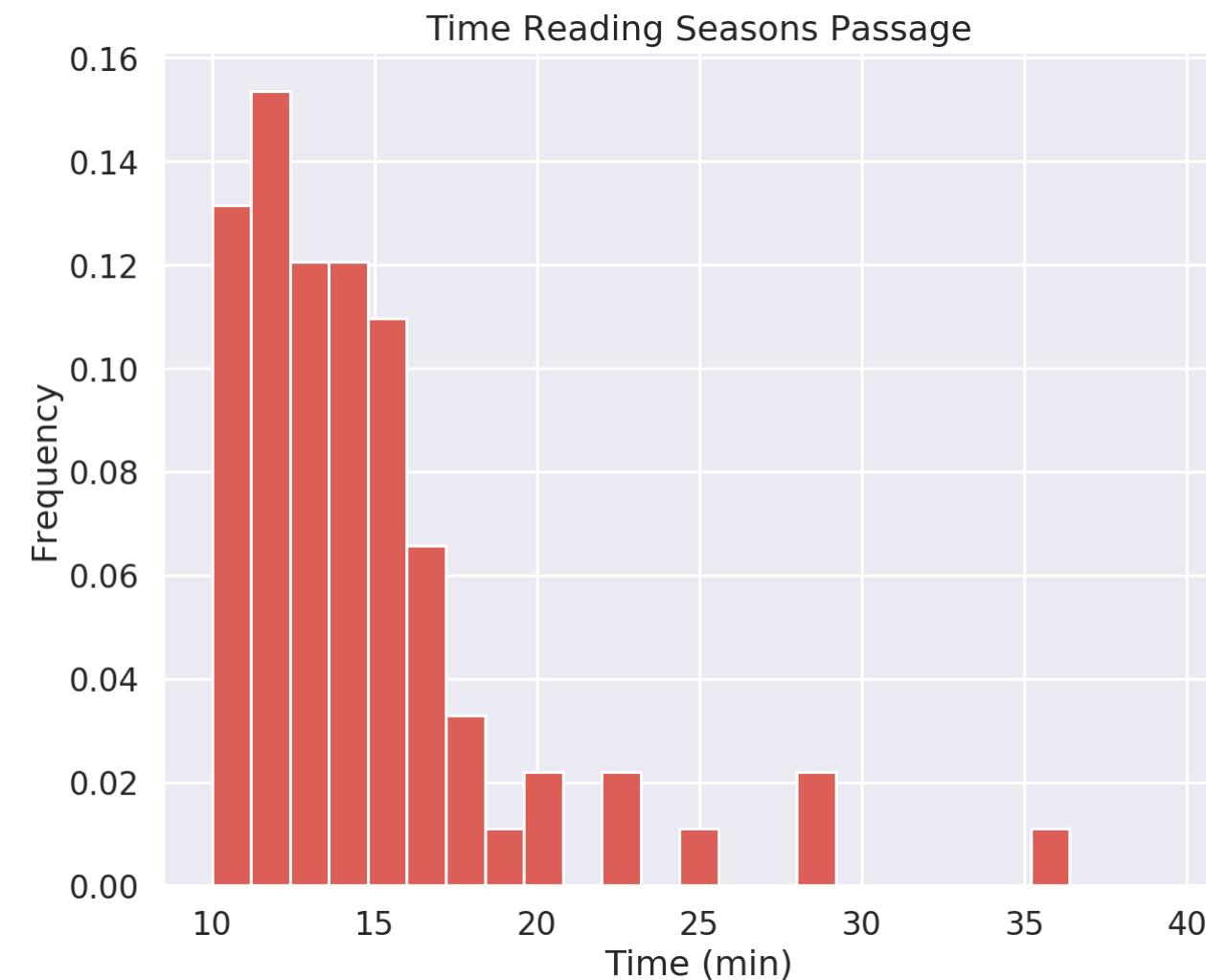
unique words in this cell:
['an', 'indefinite', 'space', 'named', 'no', 'light', 'can', 'escape', 'seen', 'as', 'through', 'telescope', 'its', 'neutrons', 'two', 'stars', 'collapse', 'the', 'ball', 'neutrons', 'schwarzs', 'radius', 'that', 'helps', 'approximate', 'seize', 'external', 'horizon', 'which', 'separates', 'inside', 'with', 'outside', 'space', 'singularity', 'enlargement', 'infinite', 'in', 'time']

The number of unique words in this cell:
36

Extra Analyses

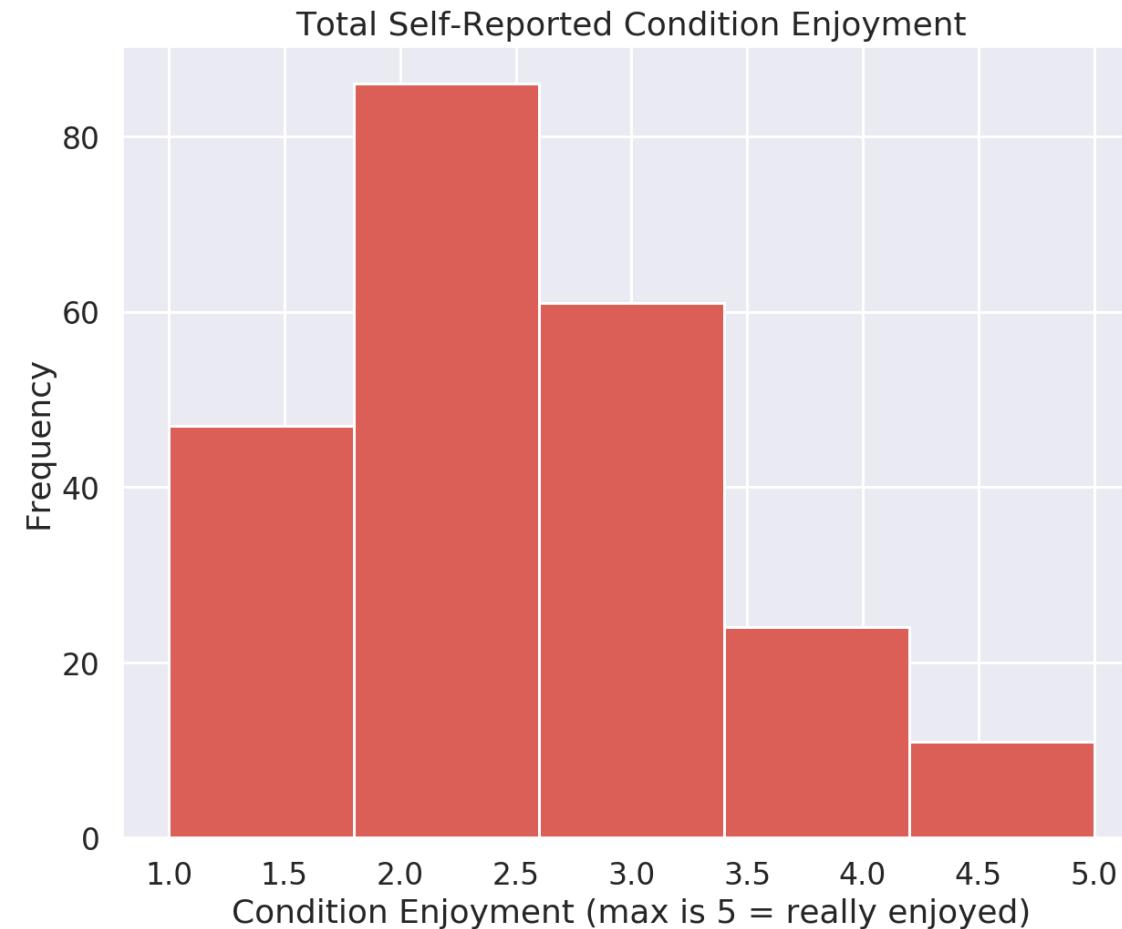
- ❖ Time spent reading
- ❖ Condition enjoyment
- ❖ Word use
 - Total
 - Unique

Time Spent Engaging with Learning Materials



$$F(3, 225) = 8.821, \quad p=0.000149$$

Condition Enjoyment

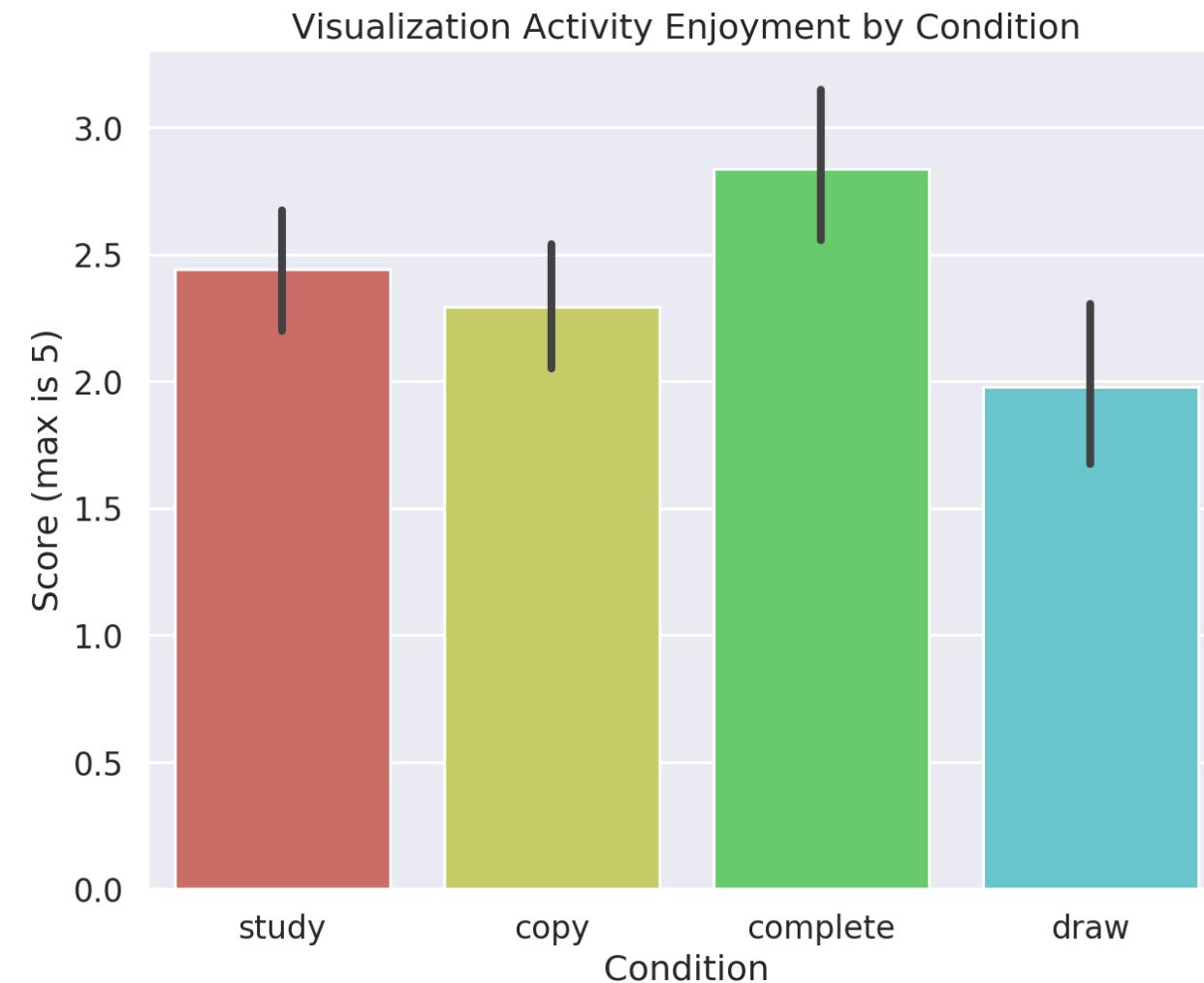


Condition Enjoyment

Mean: 2.415 standard dev: 1.075

Min: 1 Median: 2.0

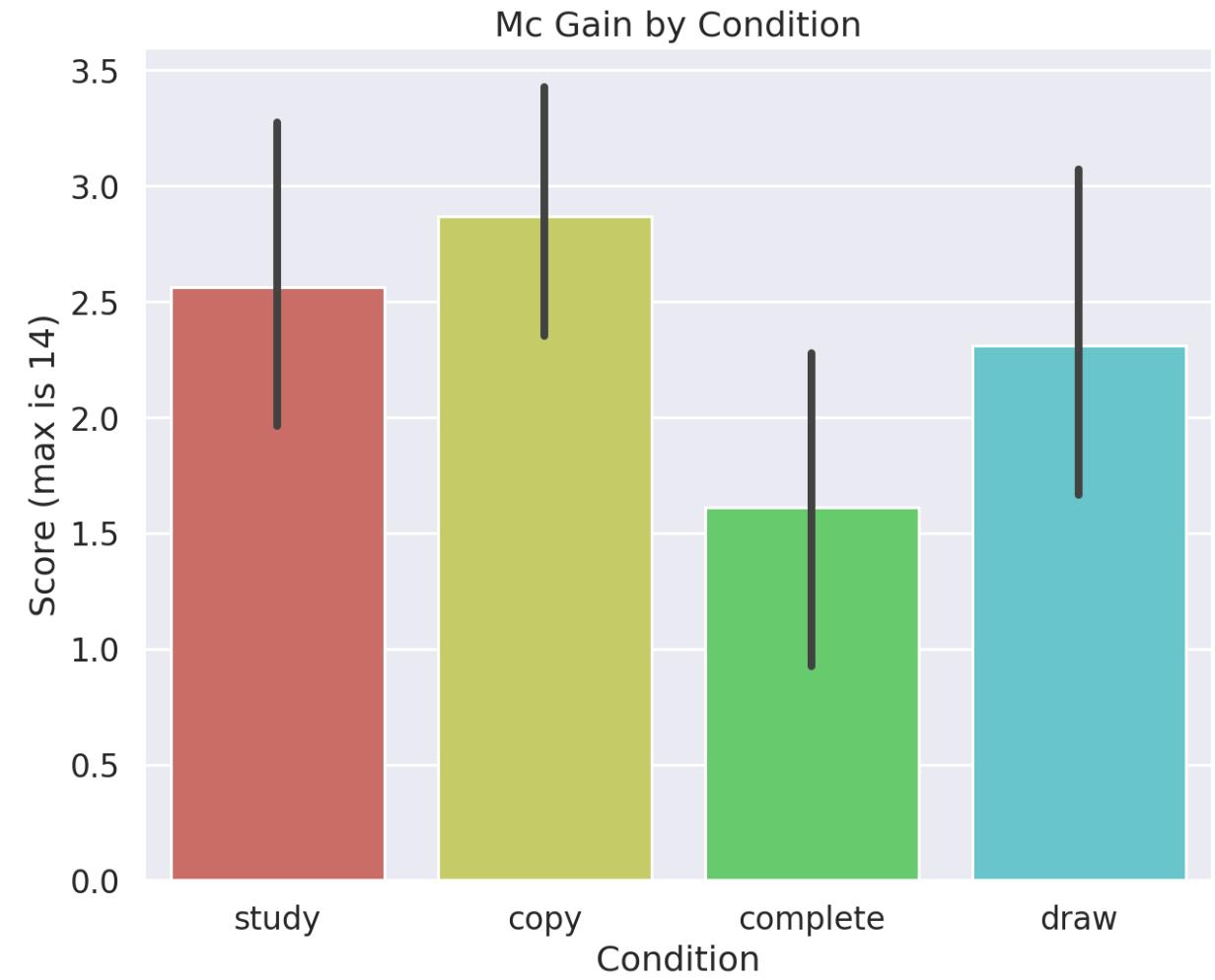
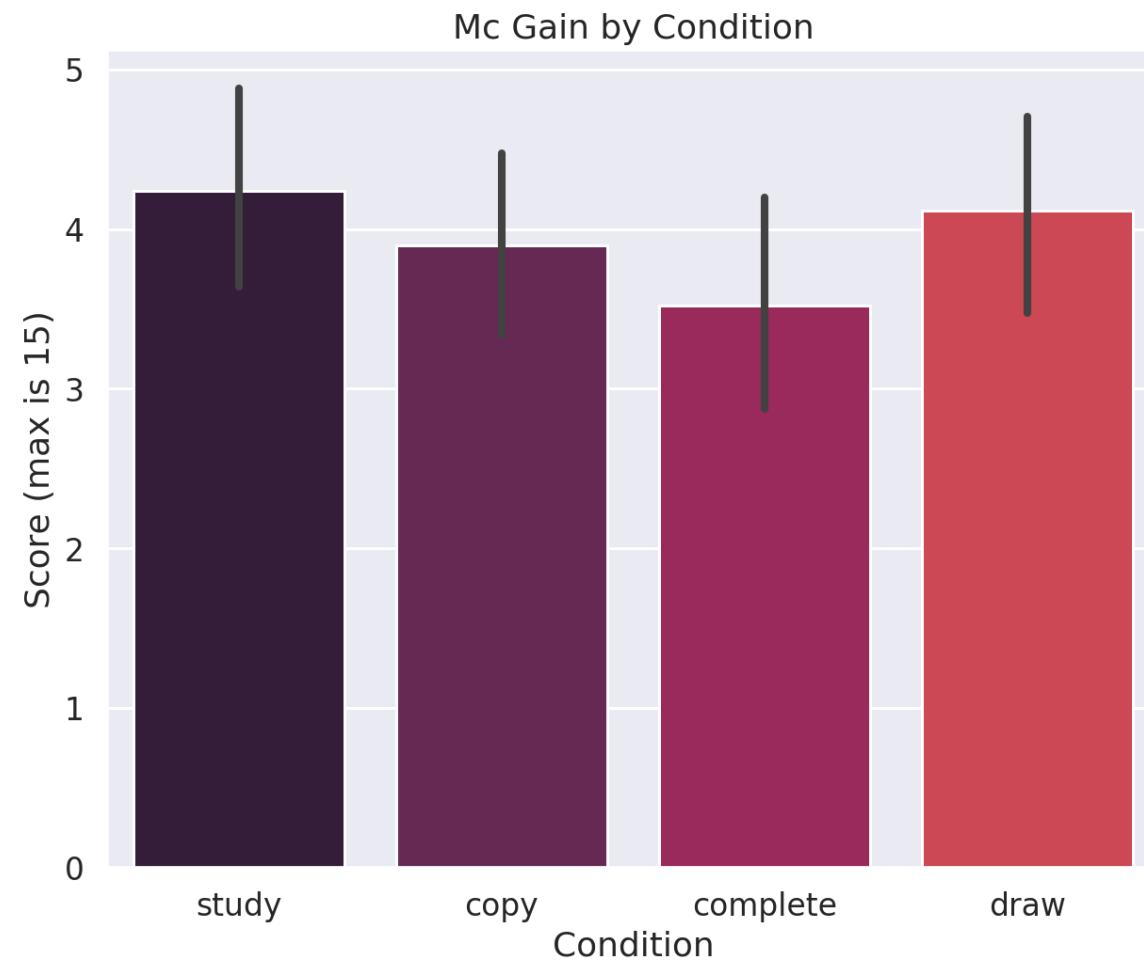
Max: 5



$$F(3, 225) = 6.329, \quad p=0.000387$$

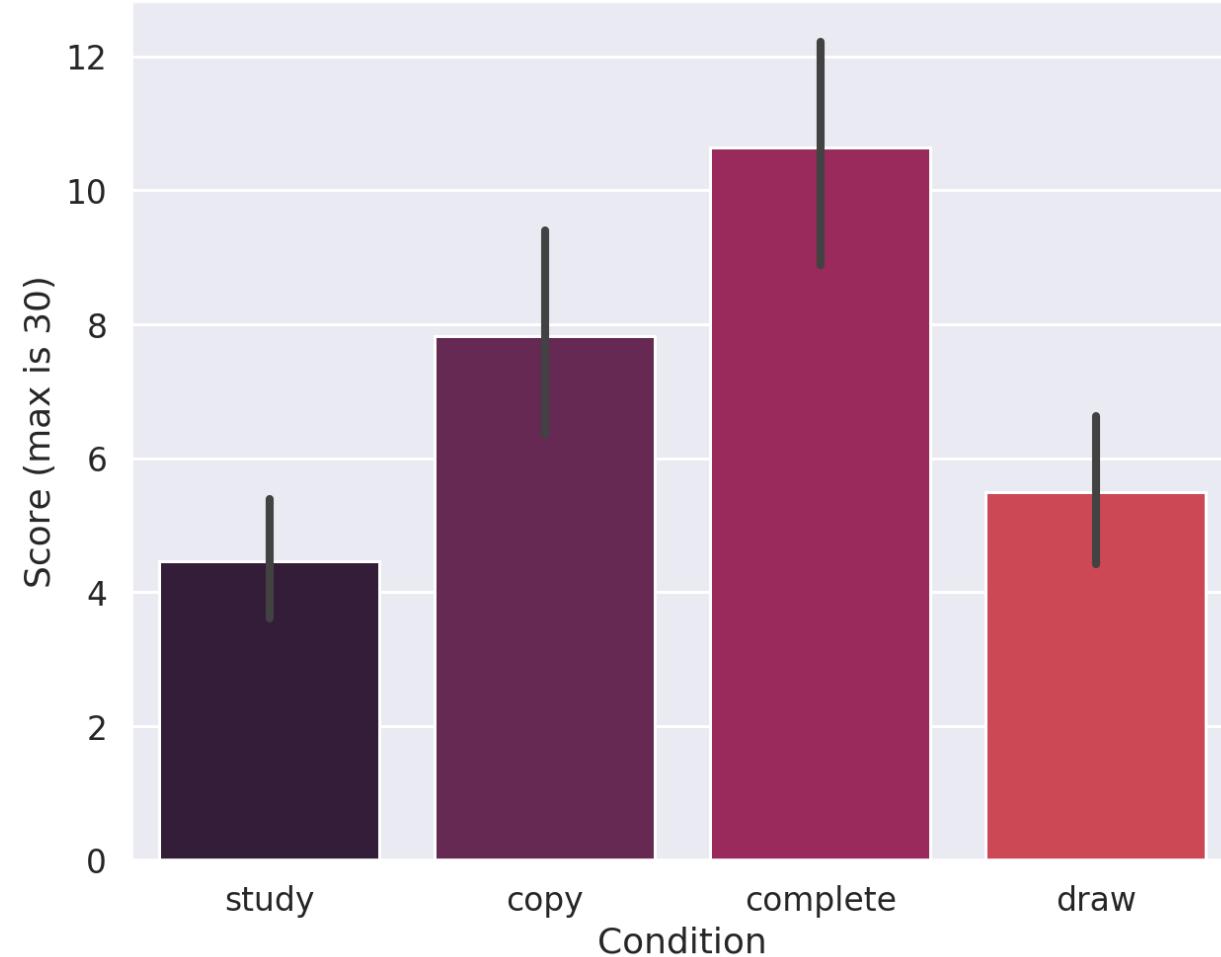
Comparisons

Black Holes vs Seasons – MC Gain

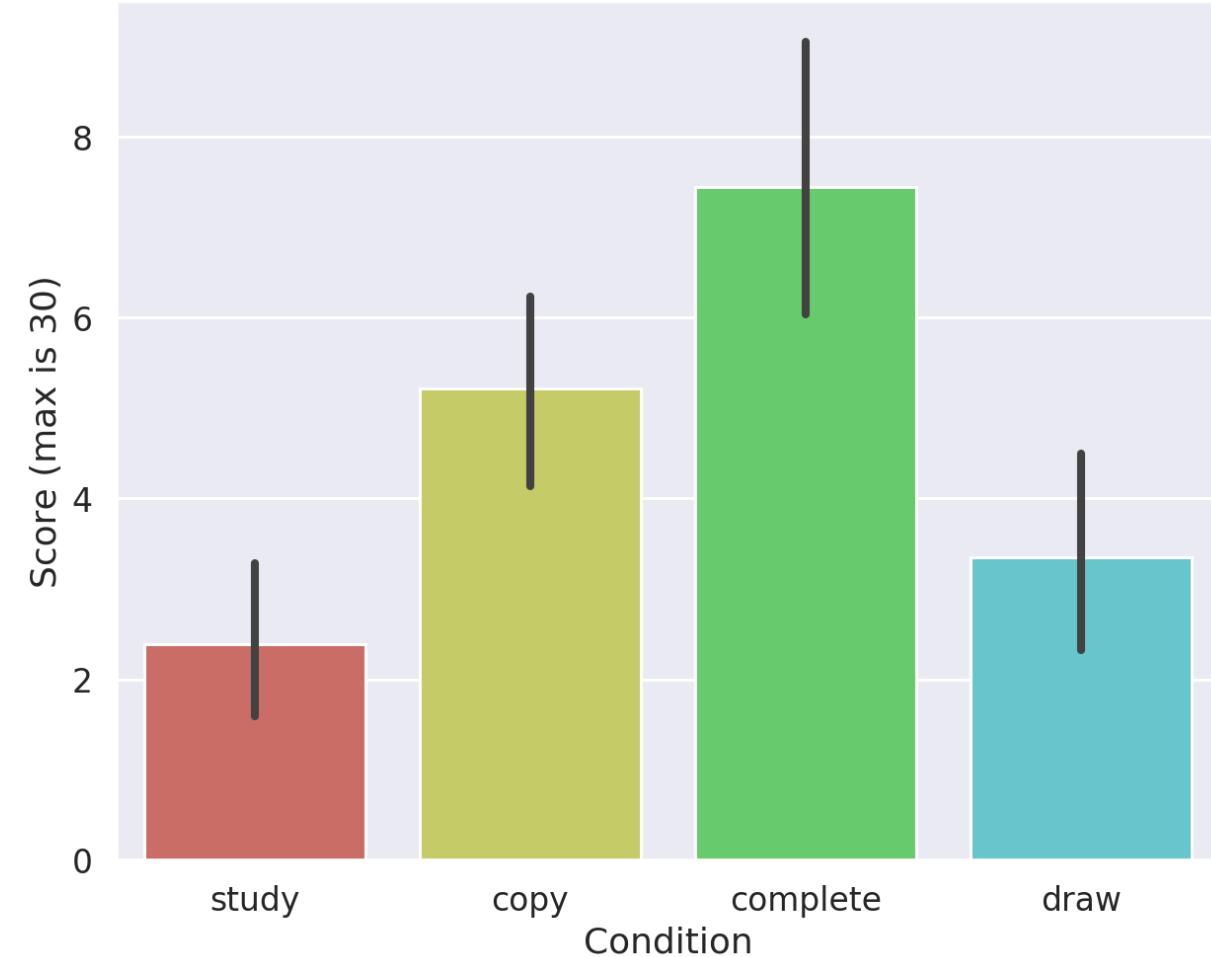


Black Holes vs Seasons – Extraneous Load

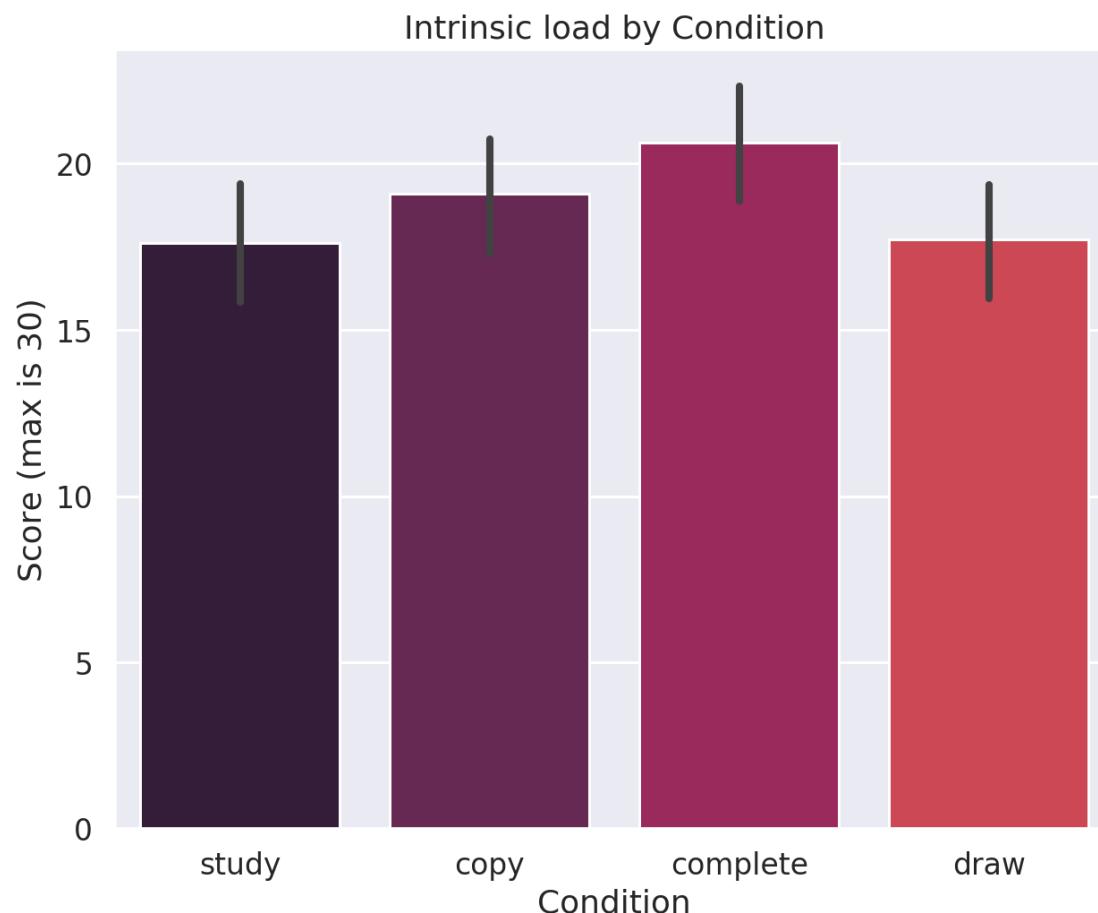
Extraneous load by Condition



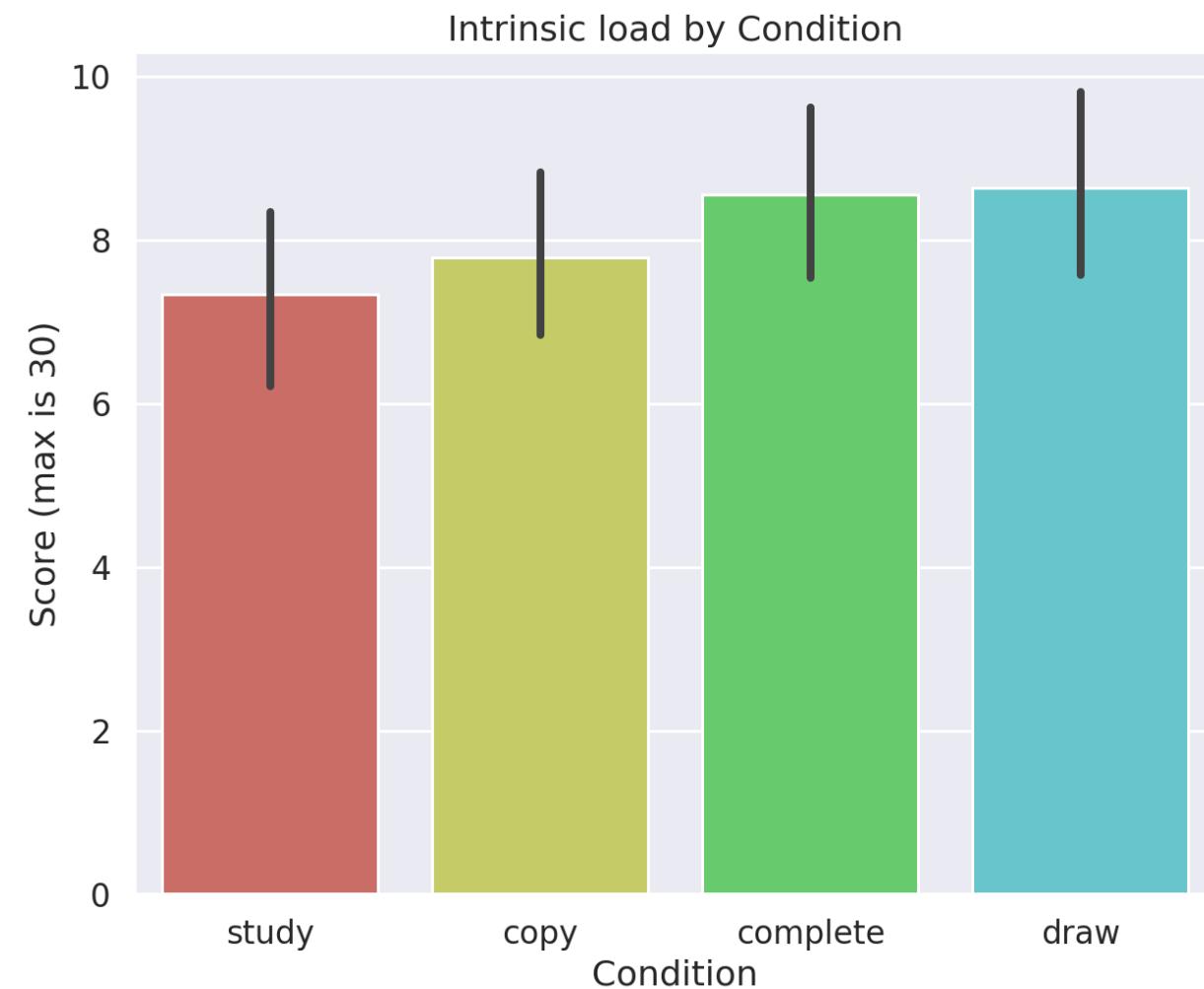
Extraneous load by Condition

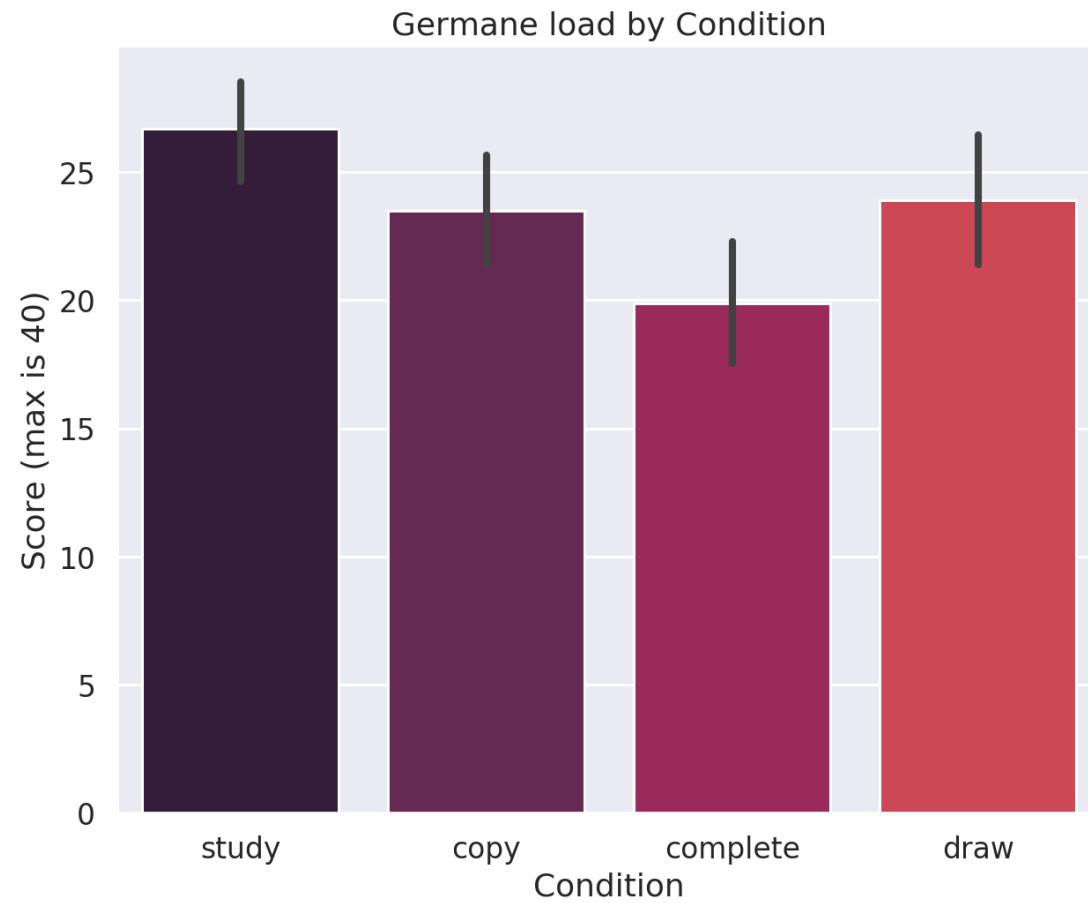


$F(3, 217) = 14.79, p = 0.0000000846$



$F(3, 217) = 2.736, p = 0.0445$





$$F(3, 217) = 5.718, p = 0.000875$$

