2YP Notebook

```
## Loading required package: boot

## Loading required package: Hmisc

## Loading required package: lattice

##
## Attaching package: 'lattice'

## The following object is masked from 'package:boot':
##
##     melanoma

## Loading required package: survival

##
## Attaching package: 'survival'

## The following object is masked from 'package:boot':
##
##     aml

## Loading required package: Formula

## Loading required package: ggplot2

##
## Attaching package: 'Hmisc'

## The following objects are masked from 'package:base':
##
##     format.pval, round.POSIXt, trunc.POSIXt, units

##
## Attaching package: 'dplyr'

## The following objects are masked from 'package:Hmisc':
##
##     combine, src, summarize

## The following objects are masked from 'package:pastecs':
##
##     first, last

## The following objects are masked from 'package:stats':
##
##     filter, lag

## The following objects are masked from 'package:base':
##
##     intersect, setdiff, setequal, union

##
## Attaching package: 'car'

## The following object is masked from 'package:dplyr':
##
##     recode
```

```
## The following object is masked from 'package:boot':
##
##     logit
```

METHODS

1. Participants

317 (69% female) English speakers aged 17 to 33 were recruited from the experimental-subject pool at a large public university in the United States (M(age) = 20.5, SD(age) = 2.19). Participants completed three activities: two graph reading tasks followed by a drawing task. In some cases (order = linear-first), participants (n = 155) completed the first graph reading task with a linear model graph, followed by the task with the triangular graph. To control for any effects of graph order on performance, an additional (n= 162) subjects completed the activities with the graphs in reverse order. Each participant was randomly assigned to one of five conditions which determined what additional information (scaffold) they received while solving the first five problems on each graph reading task: no-scaffold (control), 'what' text, 'how'-text, static-image, interactive-image. The runtime of the entire study ranged from 22 to 66 minutes (M = 40, SD = 8.56).

In addition, we ran 6 expert participants through two conditions, composed of research assistants with more than 20 hours of experience analyzing data with the triangular model graph.

2. Group Totals

Participants were randomnly assigned to task order (LMFirst, TMFirst) and Scaffold Condition (none, what-text, how-text, static image, interactive image) conditions

Task Order

Condition

LMFirst

TMFirst

All

0

29

32

61

1

31

28

59

2

30

36

66

3

30

32

62

4

35

34

69

All

155

162

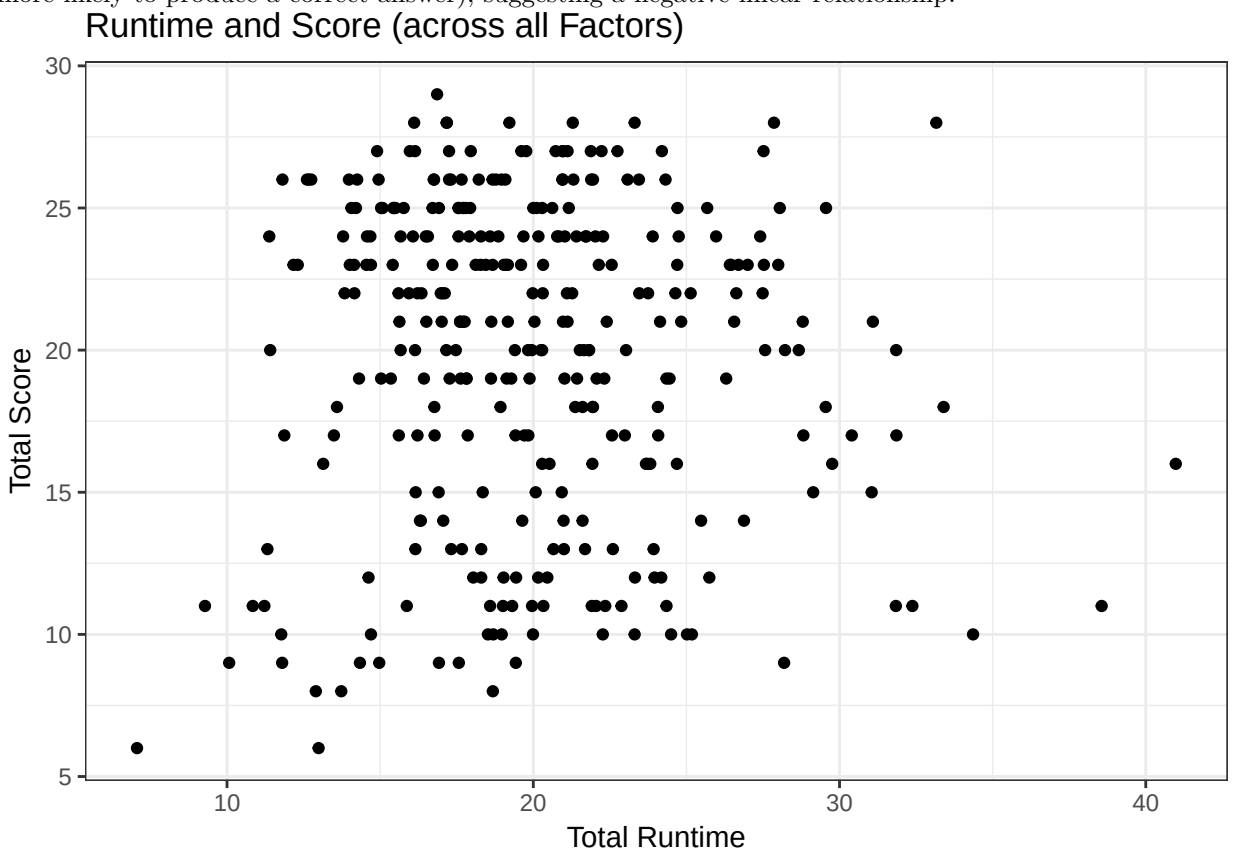
317

EXPLORATION

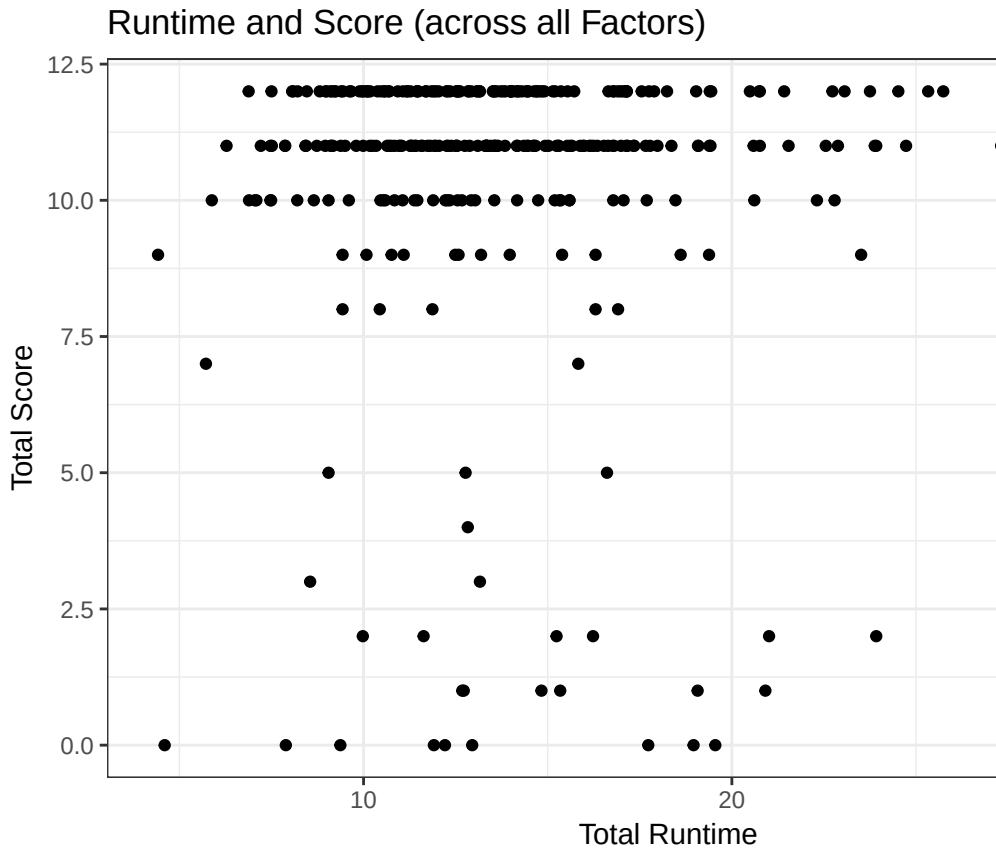
Relationship between graph time and graph score

There is no correlation between response score and response latency (in graph tasks)

We might expect to see a positive, linear relationship between score and response time: it could take longer to come up with the correct answer. Conversely, if the question is `easy`, it should take less time (and be more likely to produce a correct answer), suggesting a negative linear relationship.



Are drawing time and score correlated?



No, they do not appear to be correlated

Assumptions: DO LM scores differ significantly by order or scaffold?

No, no significant difference are found in LM scores based on scaffold or task order. This confirms the assumption that LM is a conventional representation.

```
##                   Df Sum Sq Mean Sq F value Pr(>F)
## condition          4    1.2   0.294   0.064  0.993
## order              1    2.0   1.974   0.426  0.514
## condition:order    4   10.7   2.679   0.579  0.678
## Residuals        307 1421.5   4.630
```

MEANS TABLES

Mean Response time and Score for Graphing Tasks

Score

Time

LM

TM

LM

TM

CONDITION

mean

sd

mean

sd

mean

sd

mean

sd

0

0.732

0.155

0.460

0.301

8.616

2.121

11.152

3.551

1

0.738

0.146

0.588

0.285

9.840

2.967

11.616

3.628

2

0.726

0.142

0.580

0.314

9.099

2.295

10.925

3.043

3

0.728

0.147

0.571

0.305

9.098

2.590

10.754

3.448

4

0.729

0.126

0.711

0.225

9.353

2.559

9.898

2.573

All

0.730

0.142

0.585

0.296

9.199

2.532

10.840

3.281

Mean Response time and Score for Drawing Tasks

Score

Time

CONDITION

mean

sd

mean

sd

0

0.779

0.300

13.31

3.567

1

0.859

0.233

15.13

5.307

2

0.856

0.264

14.08

4.680

3

0.884

0.183

13.77

4.553

4

0.897

0.184

13.58

4.632

All

0.856

0.238

13.96

4.592

DV: GRAPH SCORE

Mixed Effects ANOVA on SCORE

All effects are reported significant at $p < .001$. There were significant main effects of condition, $F(4,297) = 4.31$, scenario, $F(1,297) = 22.29$, and graph-type, $F(1,297) = 97.67$, There were significant interaction effects for the graph-type and the scaffold condition, $F(4,297) = 9.99$, the graph-type and scenario, $F(1,297) = 34.80$. The three-way interaction of graph-type, scaffold condition and graph-order approached significance at $F(4,297) = 2.03$, $p = 0.08$

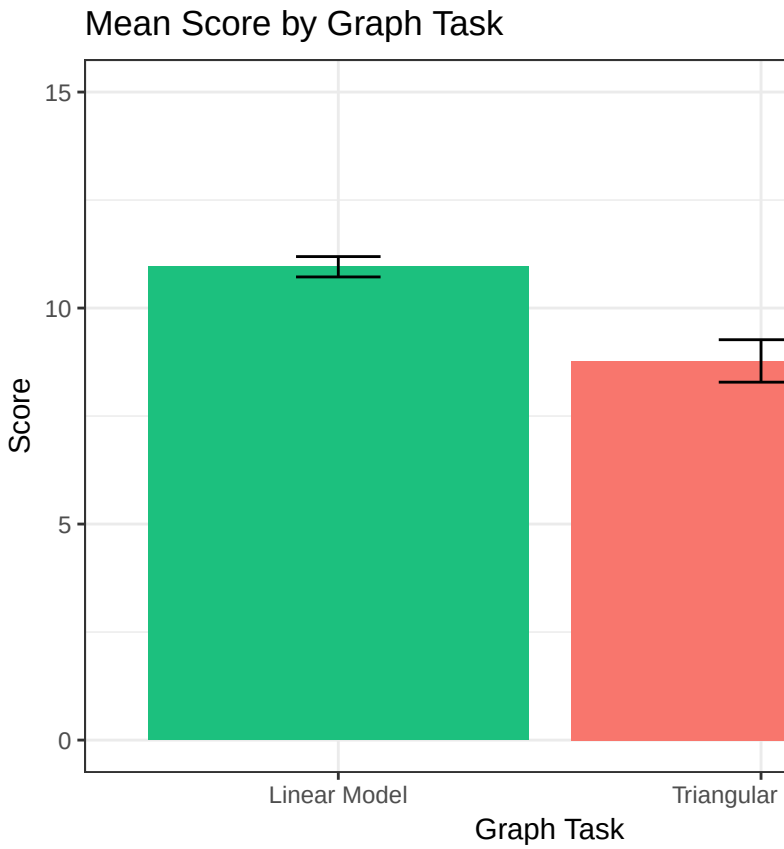
Construct a mixed ANOVA

```
## Warning: Converting "subject" to factor for ANOVA.
```

```
## Warning: Data is unbalanced (unequal N per group). Make sure you specified
## a well-considered value for the type argument to ezANOVA().
```

MIXED EFFECTS ANOVA ON SCORE
Main effect of Scaffold $F(4,297) = 4.31$, $p < .01$
Main effect of Scenario $F(1,297) = 22.29$, $p < .001$
Main effect of Graph $F(1,297) = 97.67$, $p < .001$
Interaction of Scaffold and Graph $F(4,297) = 9.99$, $p < .001$
Interaction of Graph and Scenario $F(1,297) = 34.80$, $p < .001$
Interaction of Graph and ORDER APPROACHED SIGNIFICANCE... $F(1,297) = 3.35$, $p = 0.06$

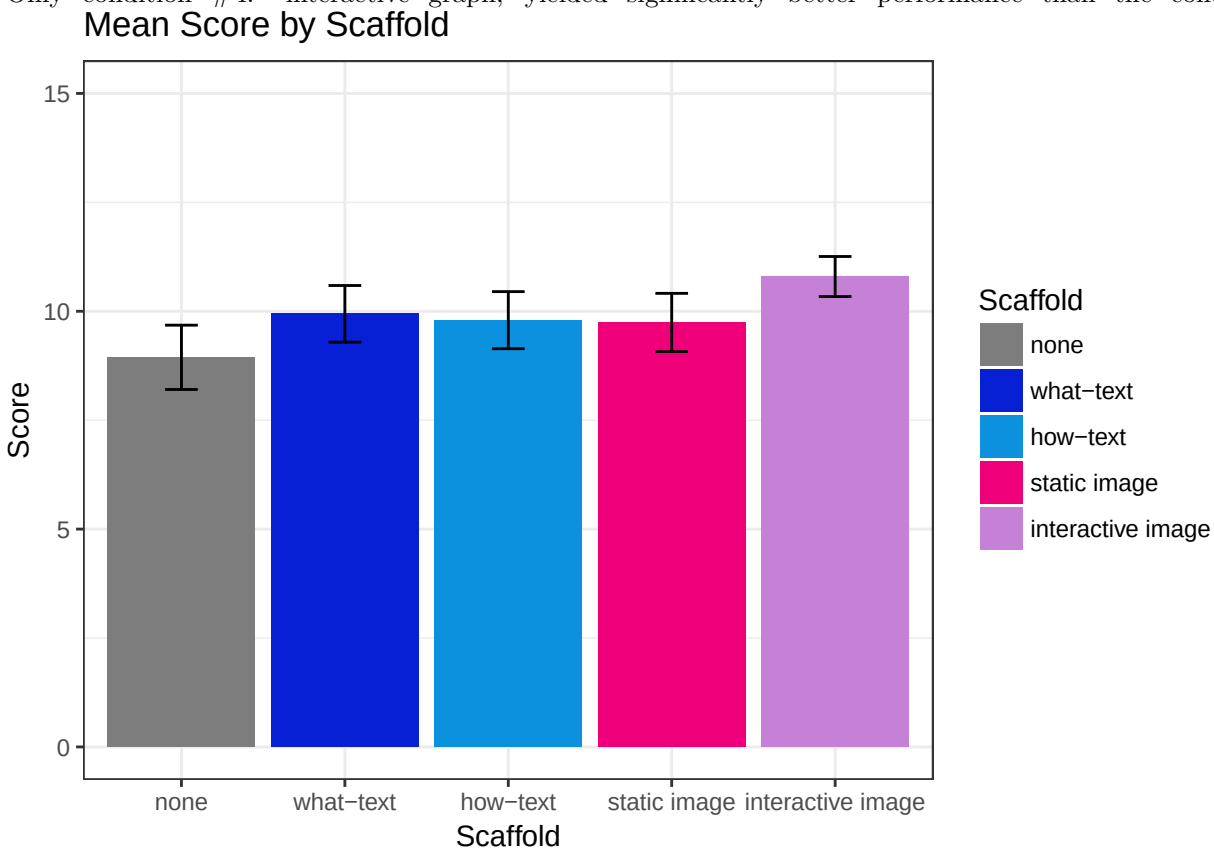
Main Effect: GRAPH



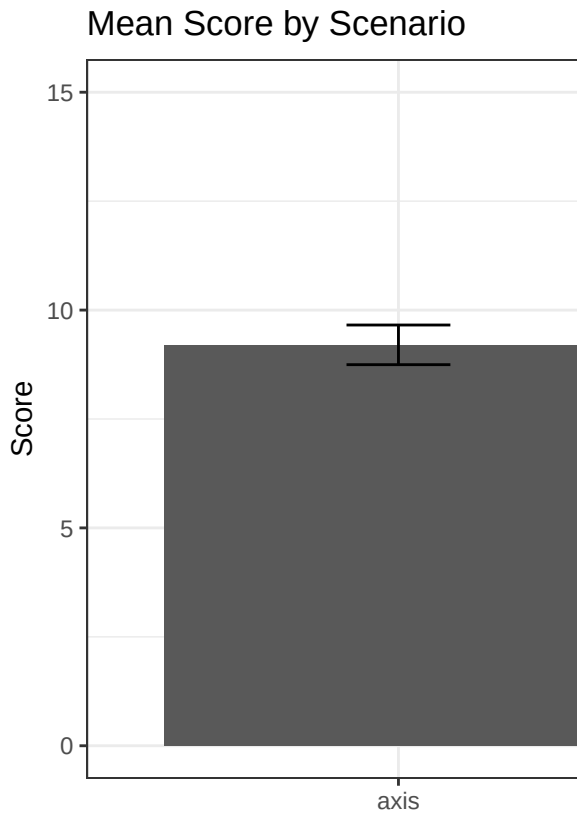
LM Model scores were significantly higher than TM scores.

Main Effect of SCAFFOLD

Only condition #4: interactive graph, yielded significantly better performance than the control



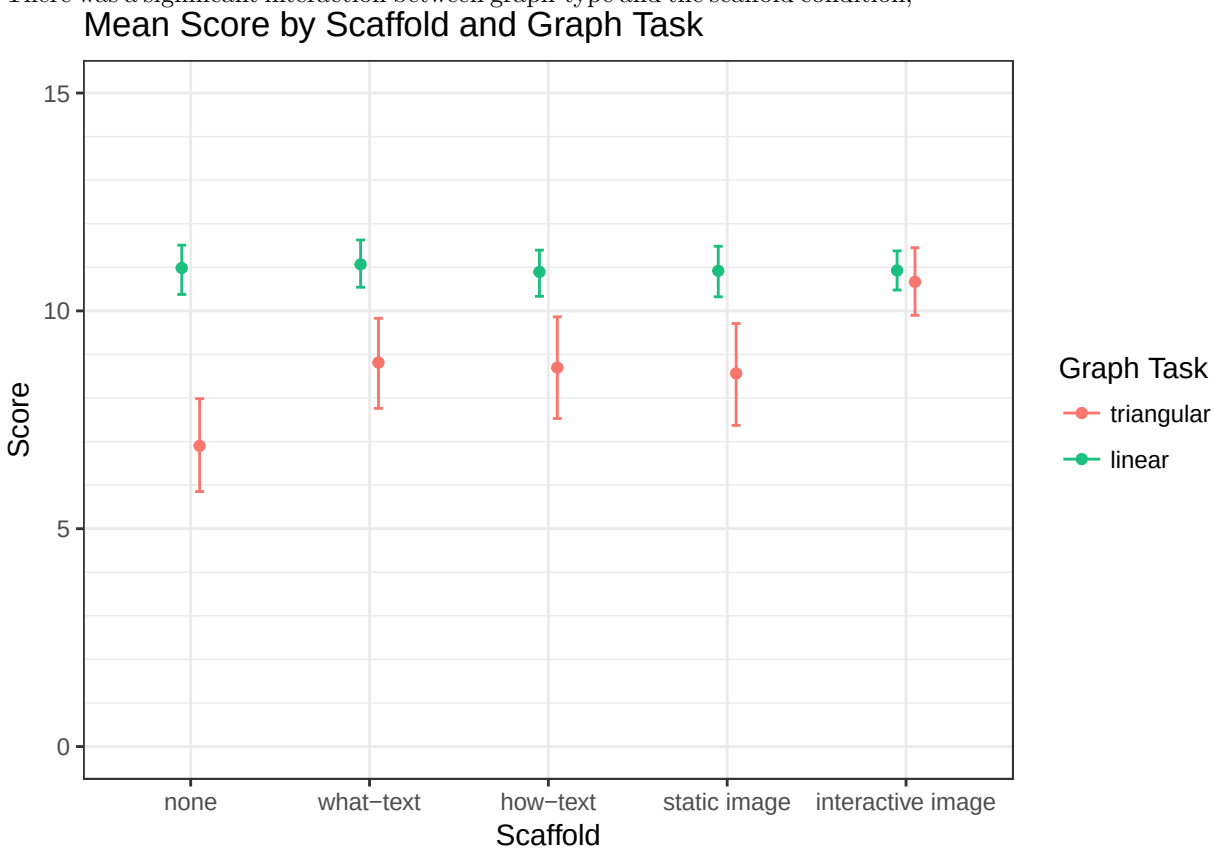
Main Effect of SCENARIO



Scores were significantly lower in the axis scenario than the longmire scenario.

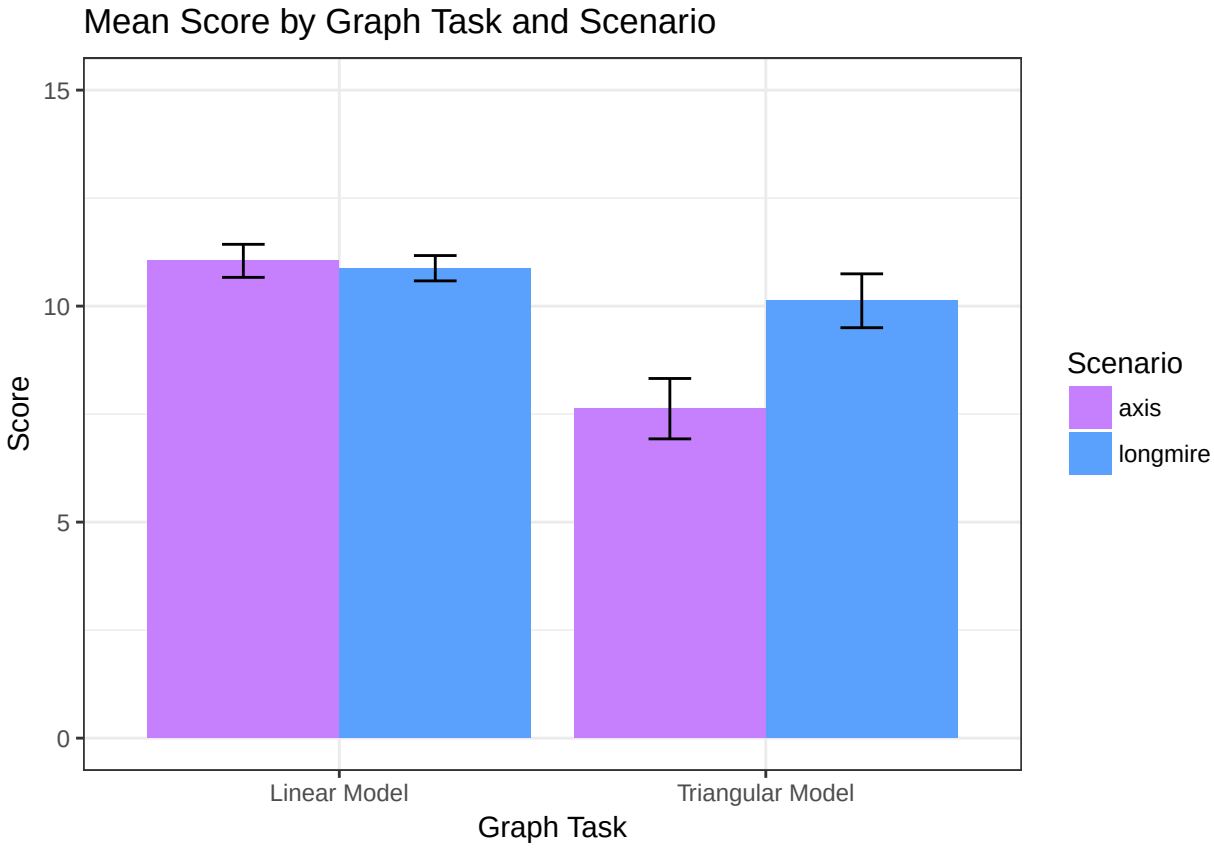
Interaction of GRAPH & SCAFFOLD

There was a significant interaction between graph-type and the scaffold condition,

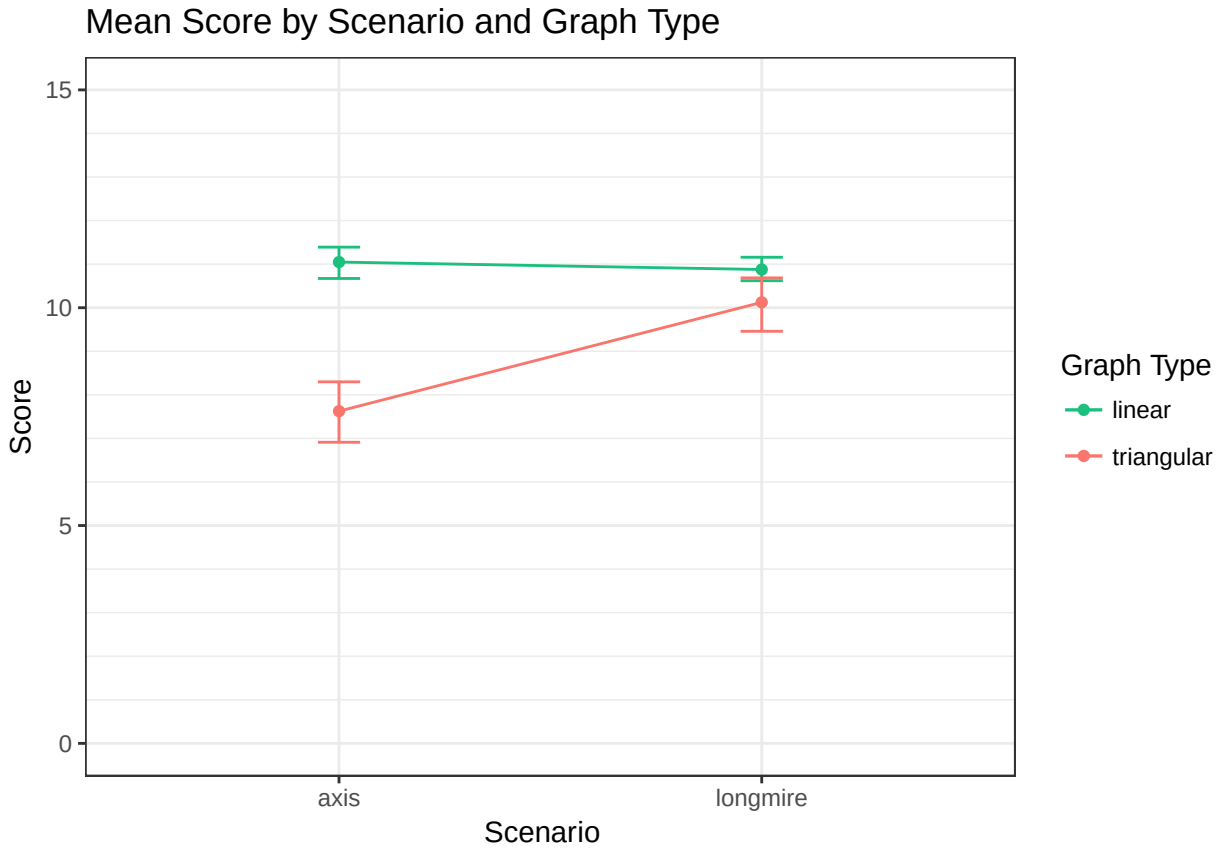


Interaction of GRAPH & SCENARIO

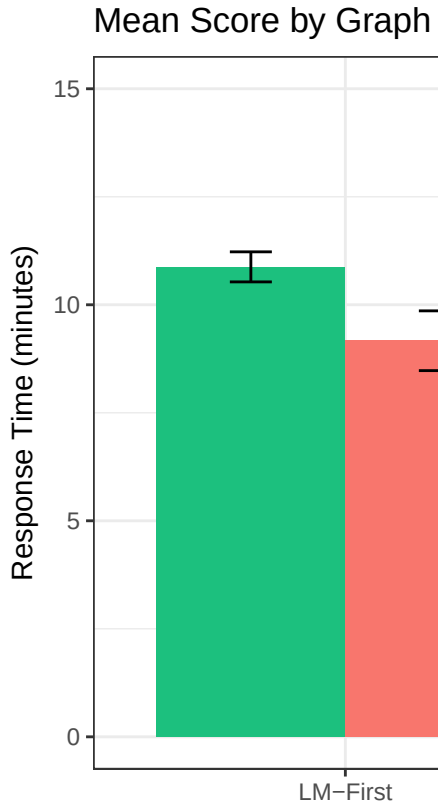
There was a significant interaction between graph-type and scenario



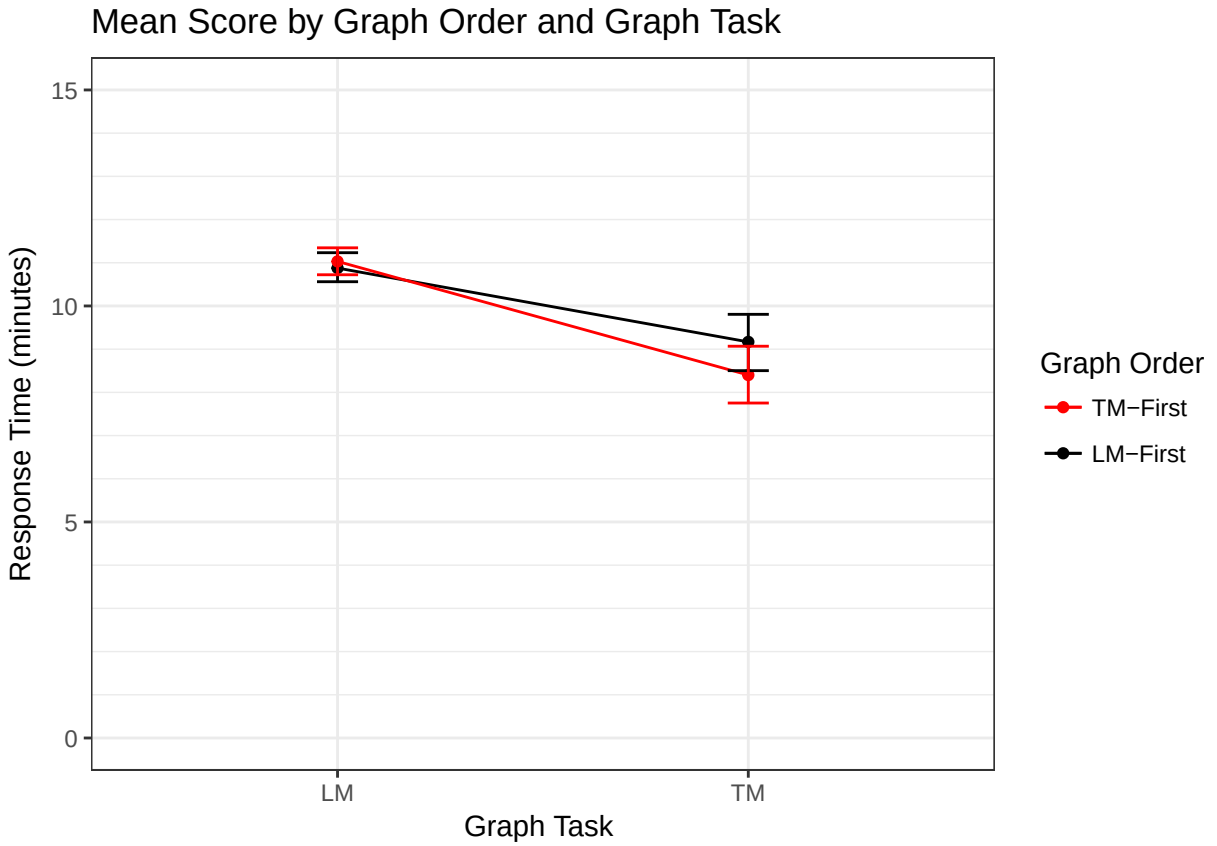

Mean Score by Scenario Order and Graph Type
15
10
5
0
Score
linear
triangular
Graph Type
Scenario
axis
longmire

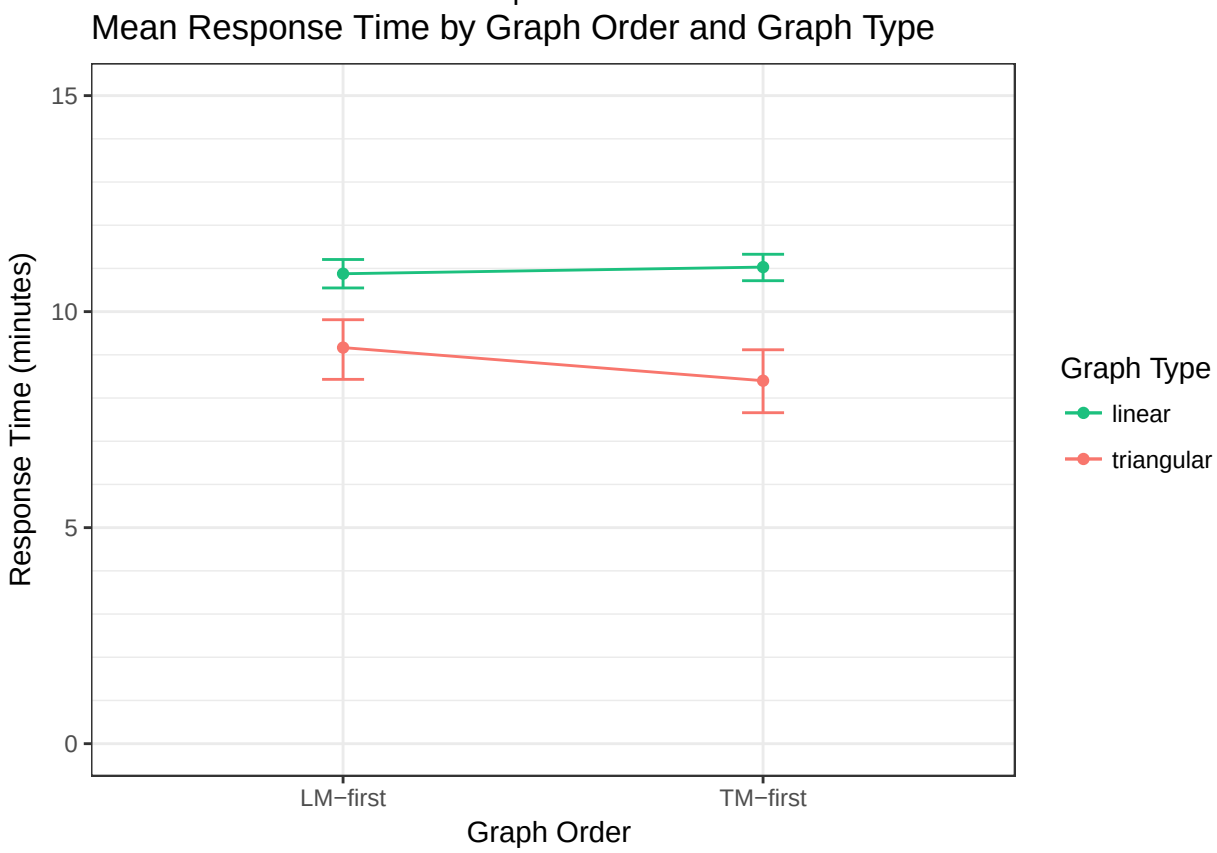

Mean Score by Scenario and Graph Type
15
10
5
0
Score
axis
longmire
Scenario
Graph Type
linear
triangular

(almost) Interaction of GRAPH & ORDER



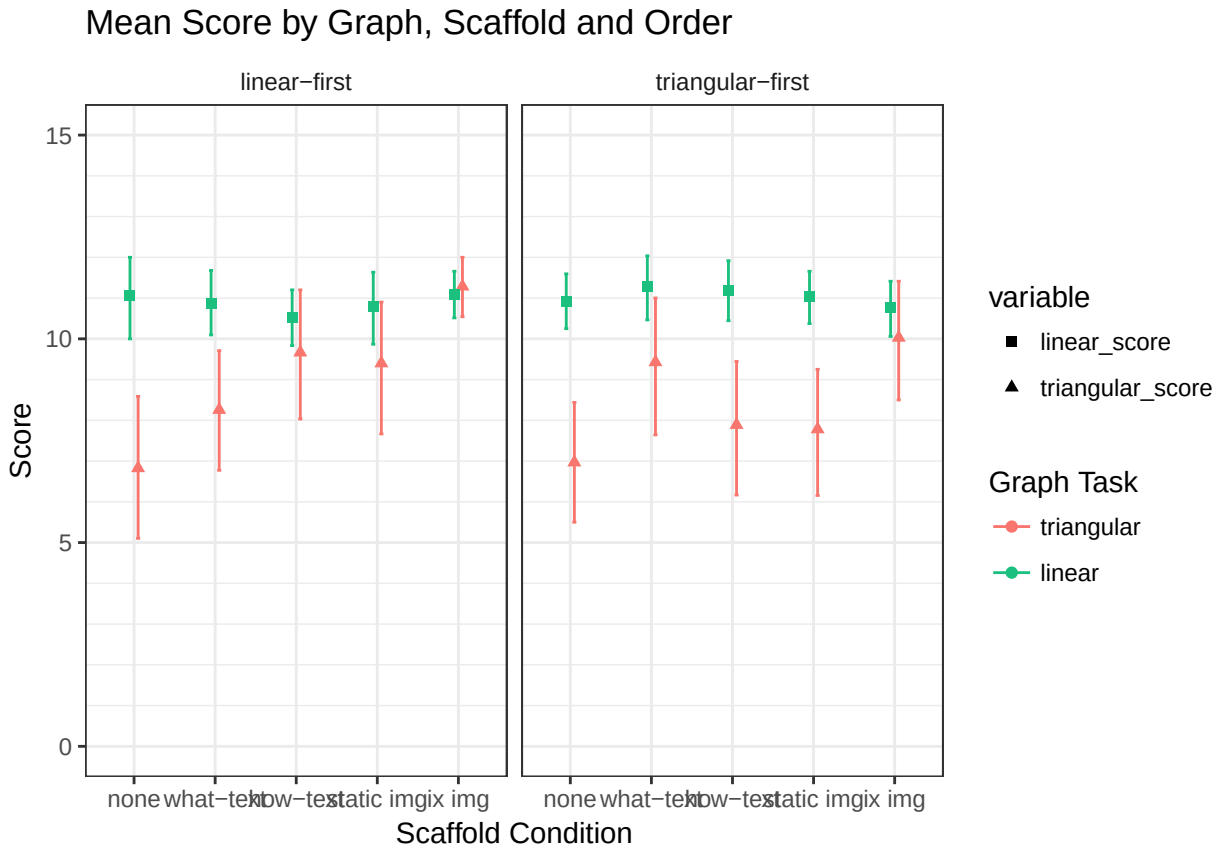
Interaction of Graph and ORDER APPROACHED significance $F(1,297) = 3.35$, $p = 0.06$

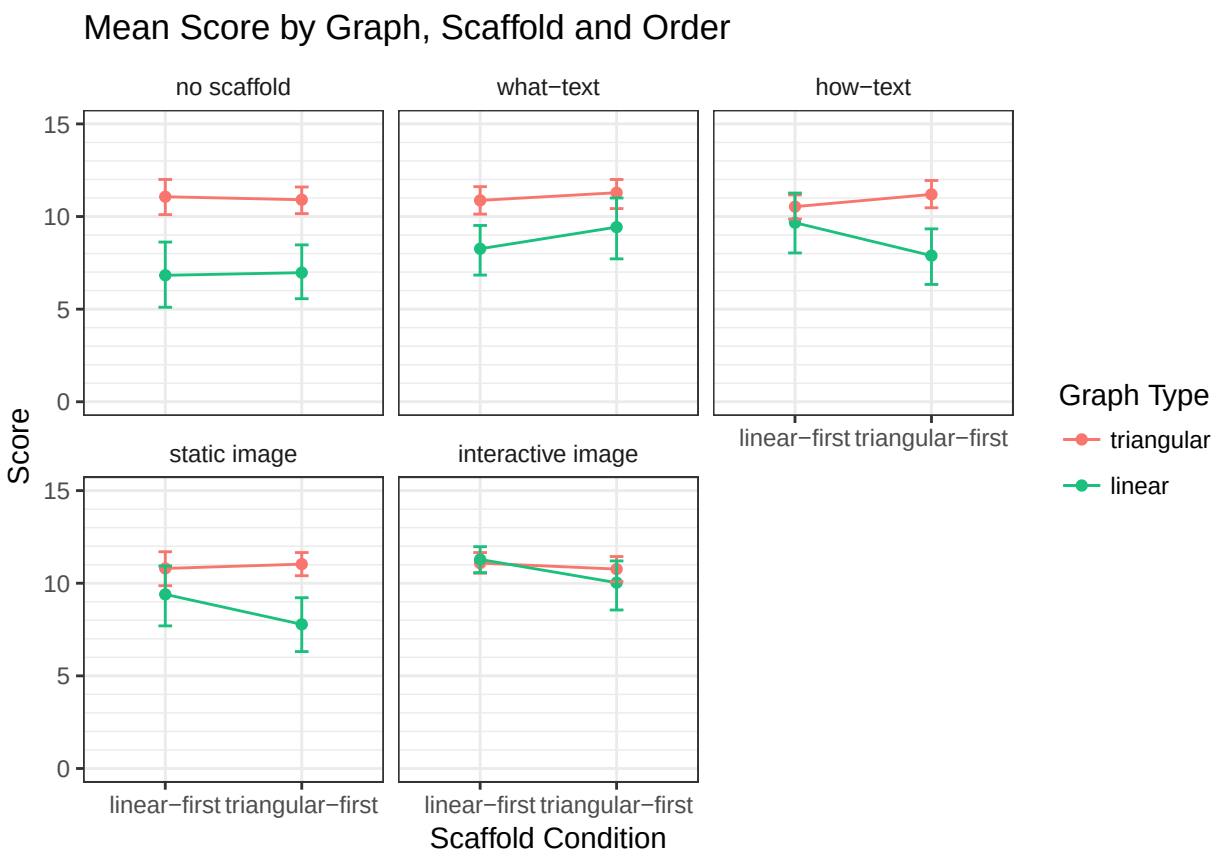

Mean Score by Graph Order and Graph Task
Response Time (minutes)
15
10
5
0
LM
TM
Graph Task
Graph Order
TM−First
LM−First

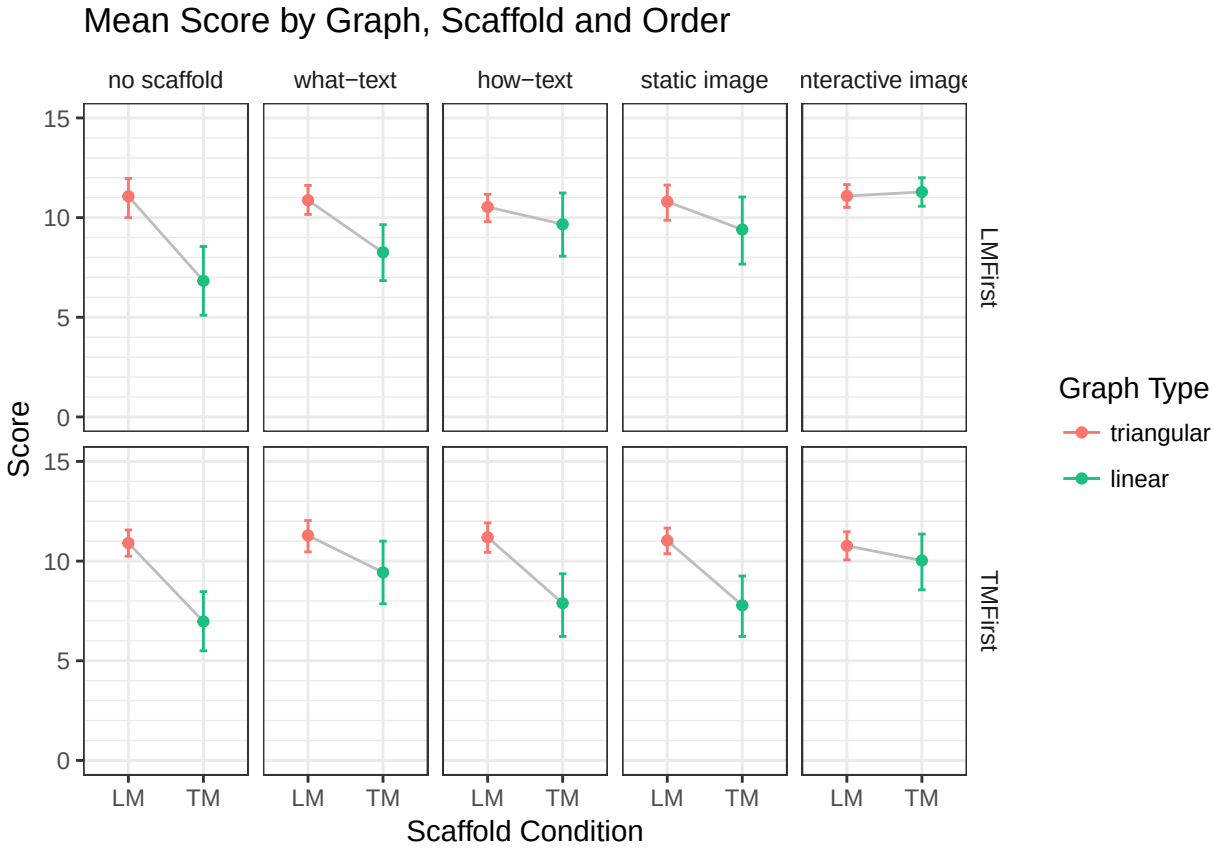

Mean Response Time by Graph Order and Graph Type
Response Time (minutes)
15
10
5
0
LM−first
TM−first
Graph Order
Graph Type
linear
triangular

Interaction of GRAPH & SCAFFOLD & ORDER

The three-way interaction of graph-type, scaffold condition and graph-order approached significance at $F(4,297) = 2.03$, $p = 0.08$




Mean Score by Graph, Scaffold and Order
no scaffold
what−text
how−text
static image
interactive image
Score
15
10
5
0
linear−first
triangular−first
Scaffold Condition
Graph Type
triangular
linear


Mean Score by Graph, Scaffold and Order
no scaffold
what−text
how−text
static image
nteractive image
LMFirst
TMFirst
Score
15
10
5
0
LM
TM
Scaffold Condition
Graph Type
triangular
linear

DV: RESPONSE TIME

Construct a mixed effects ANOVA on TIME

All effects are reported significant at $p < .001$. There was a significant main effect of graph-type, $F(1,297) = 70.72$, There were significant interaction effects for the graph-type and the scaffold condition, $F(4,297) = 3.48$, the graph-type and graph-order, $F(1,297) = 31.37$, and graph-type and scenario, $F(1,297) = 10.4$. The three-way interaction of graph-type, scaffold condition and graph-order approached significance at $F(4,297) = 2.23$, $p = 0.06$

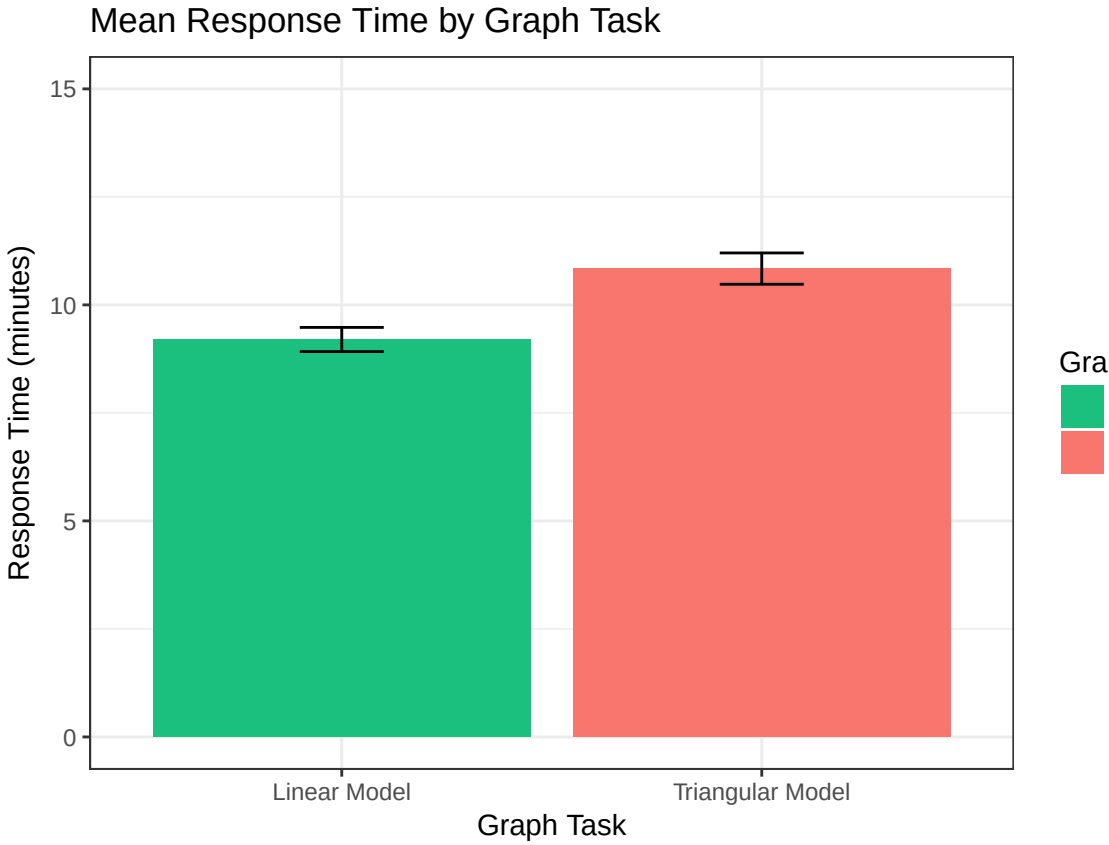
1. Explore descriptives for each factor
2. Construct contrasts
3. compute the ANOVA model

```
## Warning: Converting "subject" to factor for ANOVA.
```

```
## Warning: Data is unbalanced (unequal N per group). Make sure you specified
## a well-considered value for the type argument to ezANOVA().
```

RESULTS OF MIXED EFFECTS ANOVA ON RESPONSE TIME suggest... X significant main-effect of graph task $F(1,297) = 110.67$, $p < .001$ X significant interaction between graph & scaffold $F(4,297) = 3.48$, $p < .001$ X significant interaction between graph and order, $F(1,297) = 44.20$, $p < .001$ X significant interaction between graph and scenario, $F(1,297) = 8.28$, $p < .001$

Main effect of GRAPH

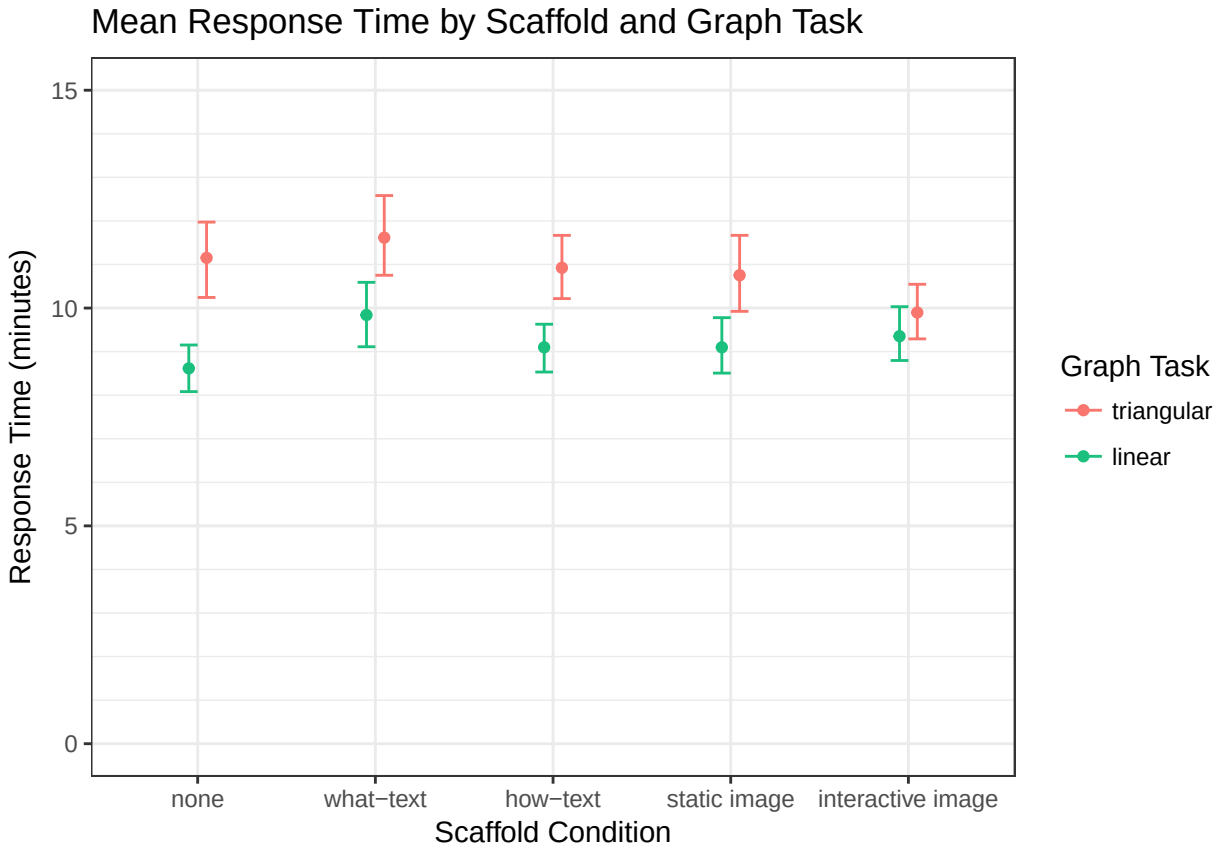


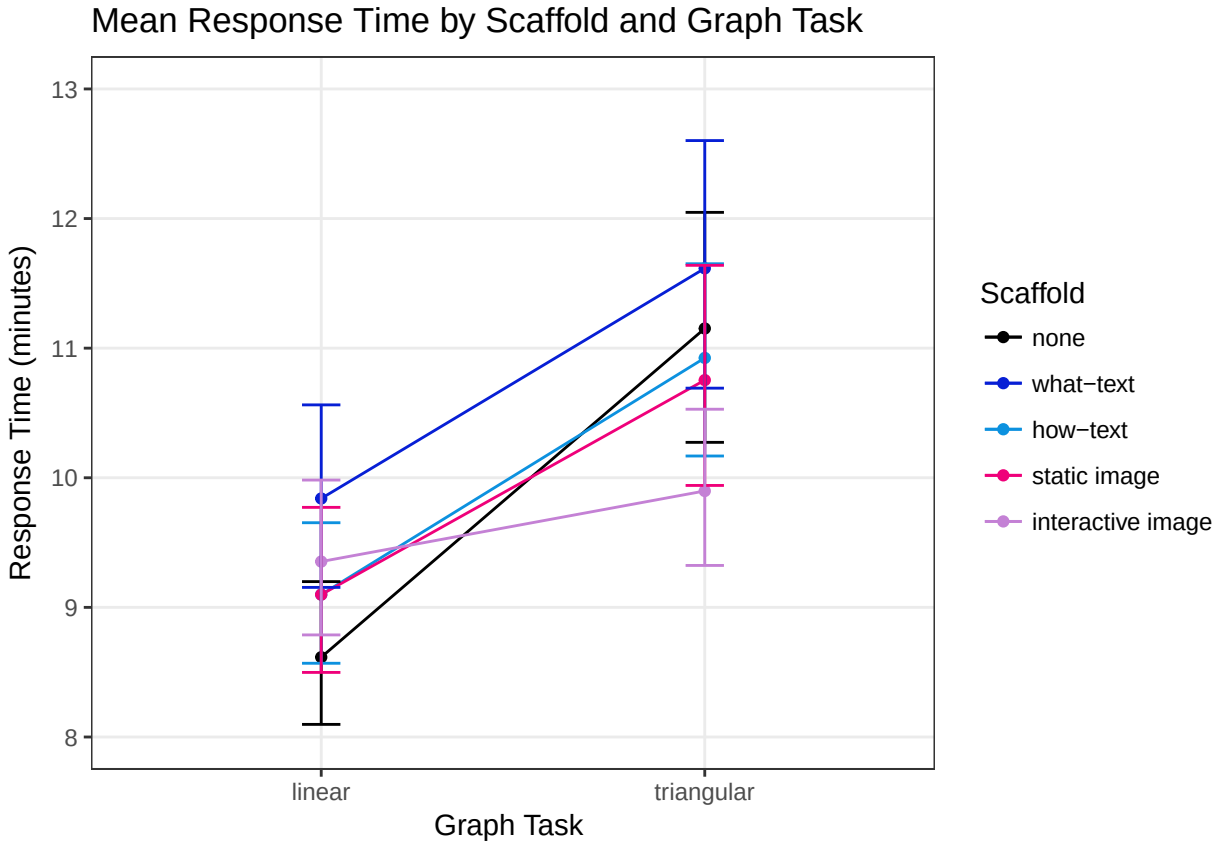
`Main Effect: Graph Type`

Across all scaffold conditions, participants spent on average 9.2 minutes on the linear model task, and 10.8 minutes on the triangular model task. The significant main effect of graph type suggests that the full range

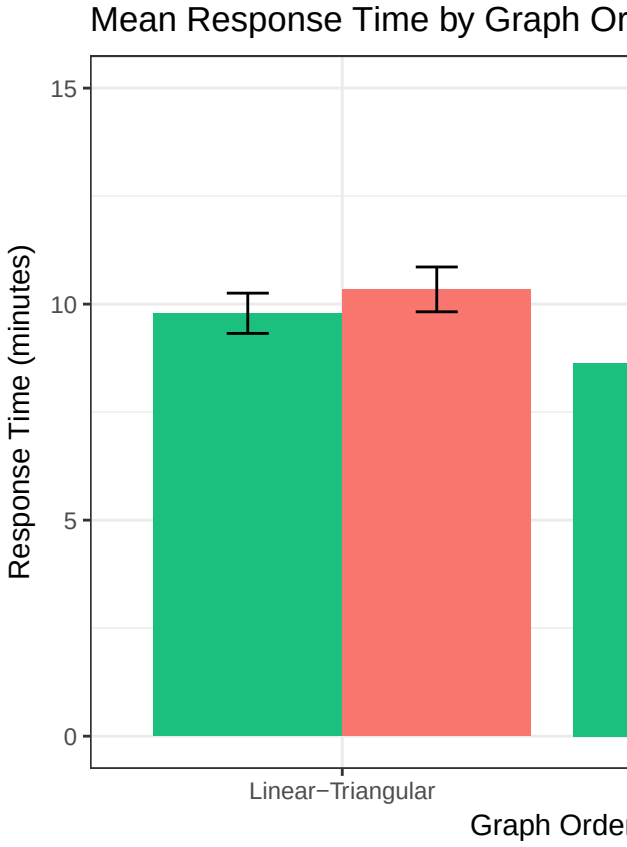
of scaffold techniques were not effective enough, on the whole, to realize the potential performance gains with the Triangular Model suggested in [CITE QIANG ET AL].

Interaction of GRAPH and SCAFFOLD

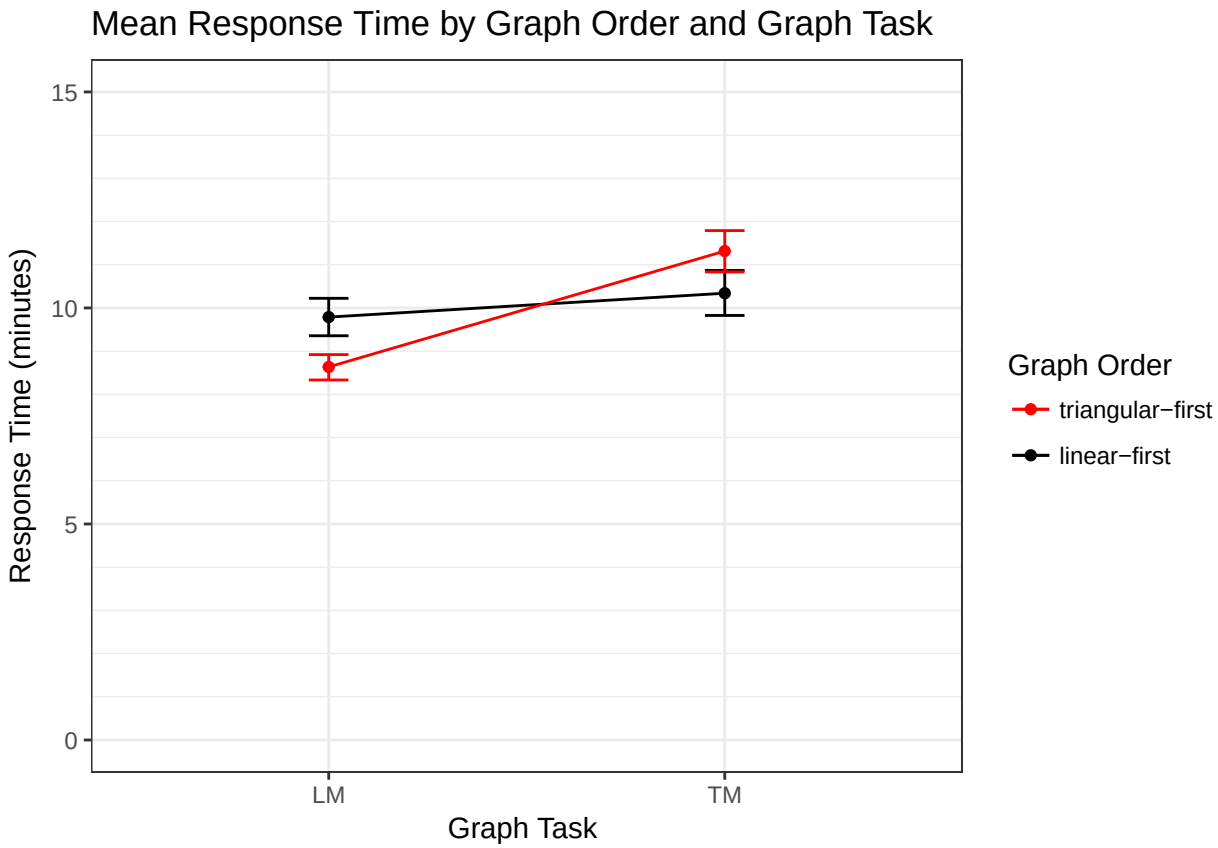

Mean Response Time by Scaffold and Graph Task
Response Time (minutes)
15
10
5
0
none
what−text
how−text
static image
interactive image
Scaffold Condition
Graph Task
triangular
linear

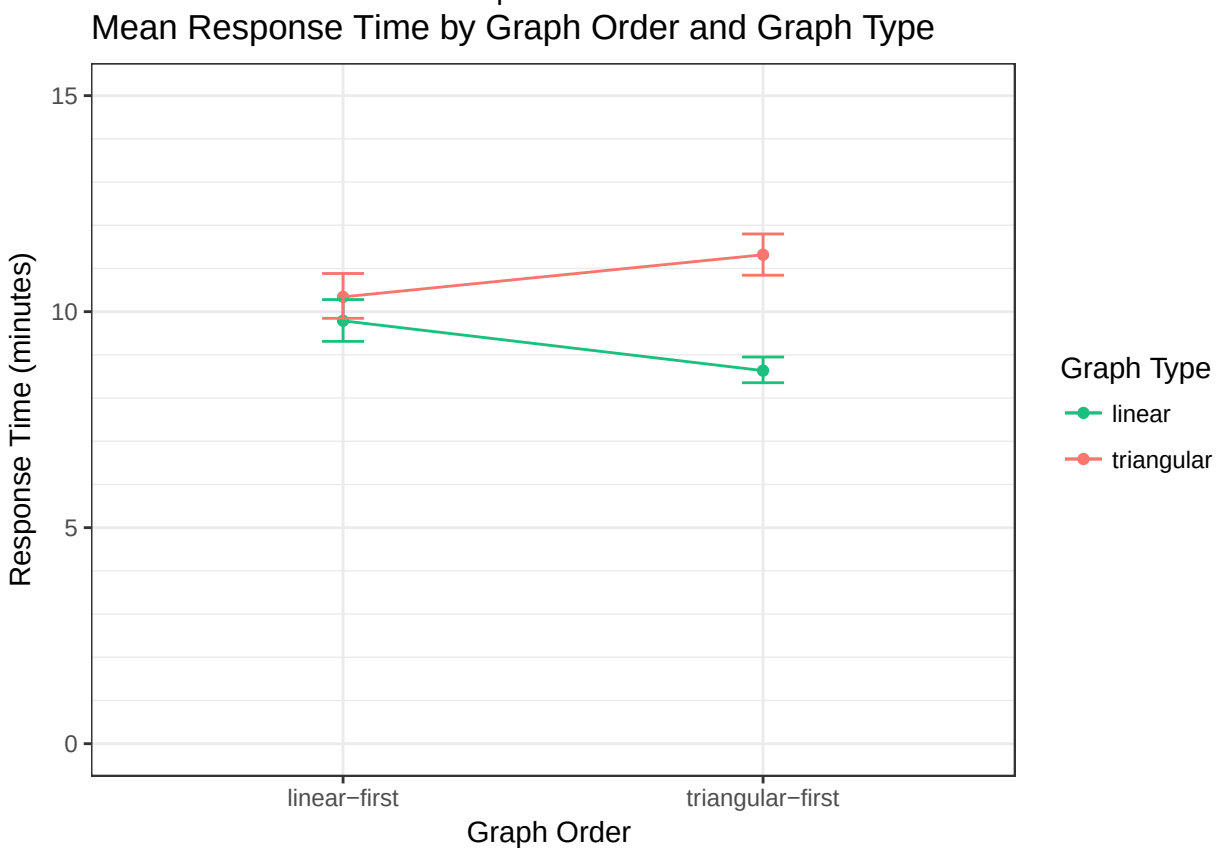

Mean Response Time by Scaffold and Graph Task
Response Time (minutes)
13
12
11
10
9
8
linear
triangular
Graph Task
Scaffold
none
what−text
how−text
static image
interactive image

Interaction of GRAPH and ORDER

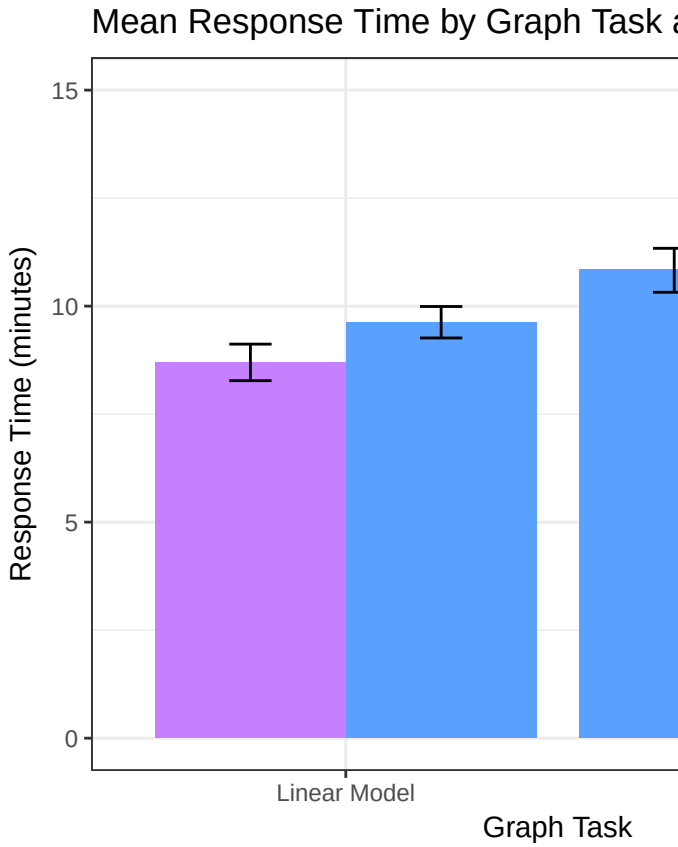


There was a significant interaction between graph-type and graph-order,

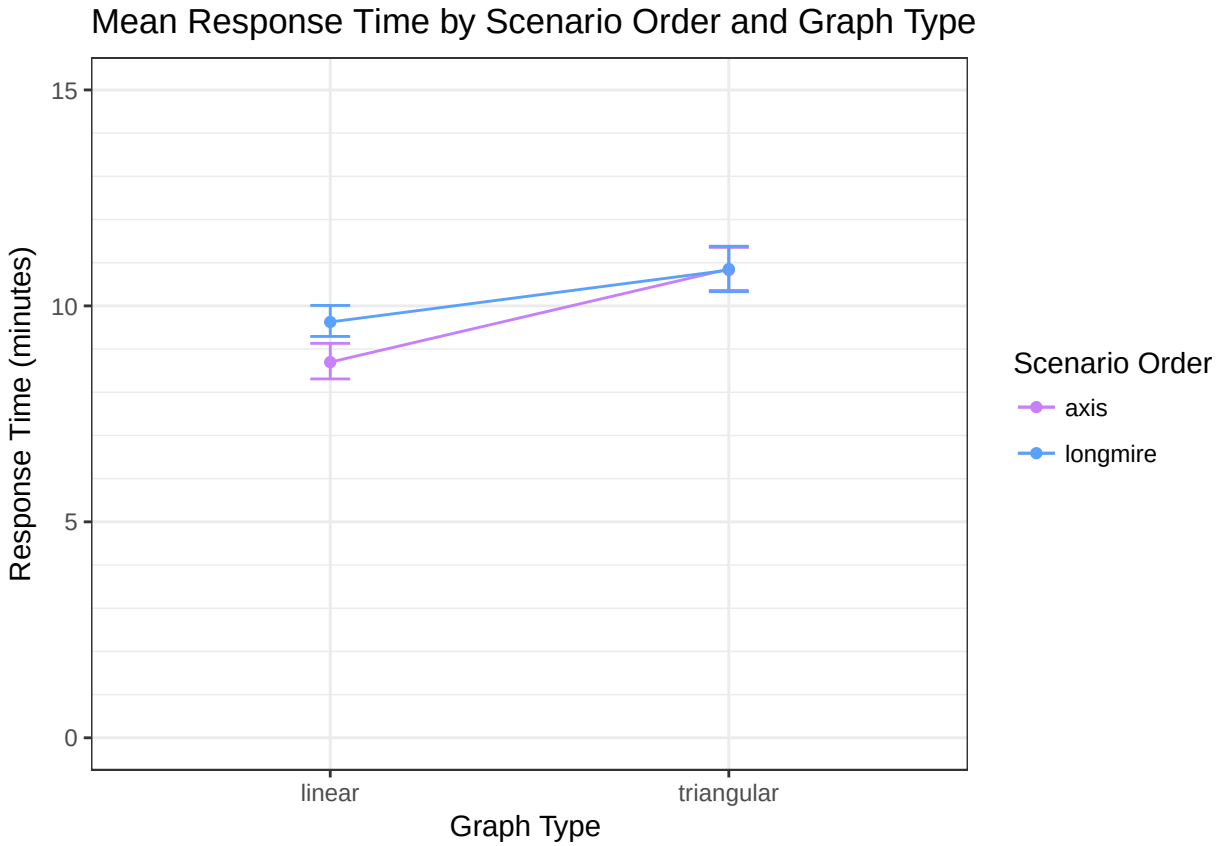

Mean Response Time by Graph Order and Graph Task
Response Time (minutes)
15
10
5
0
LM
TM
Graph Task
Graph Order
triangular−first
linear−first

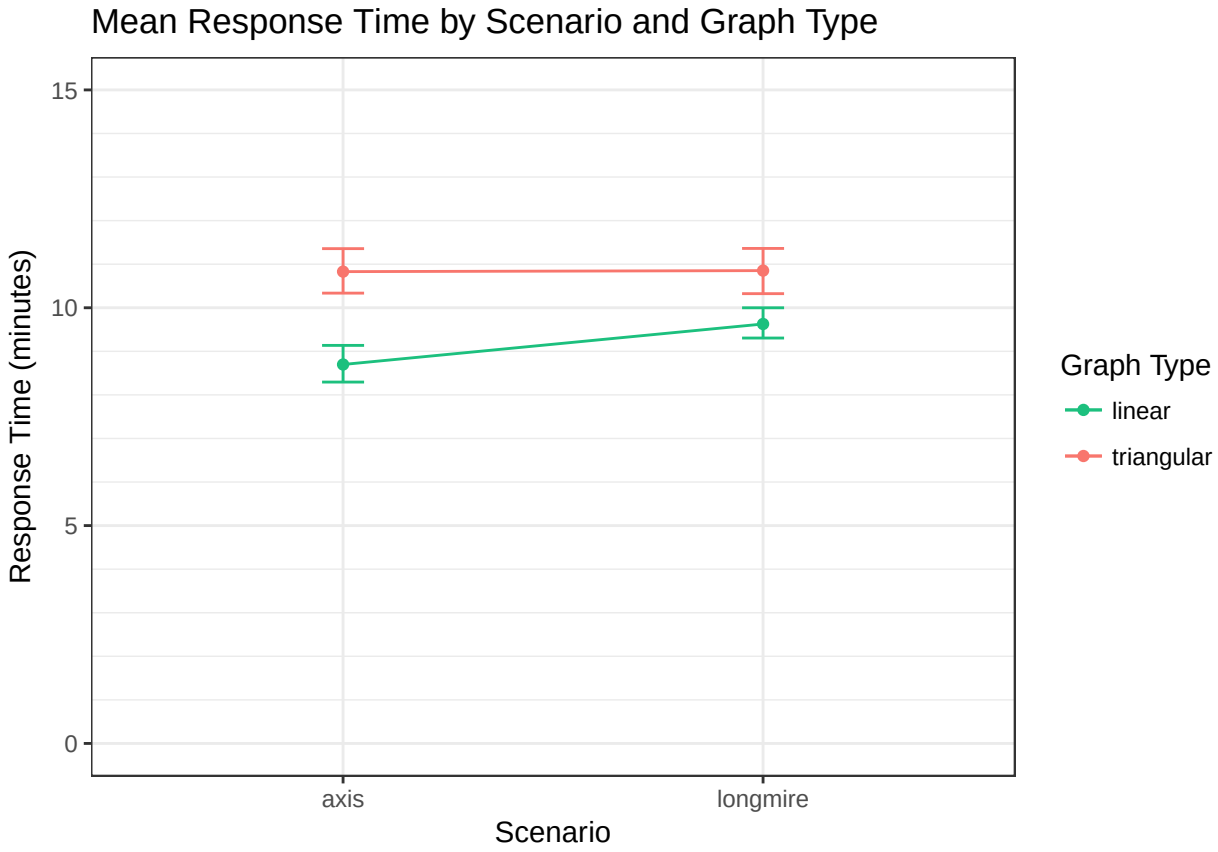

Mean Response Time by Graph Order and Graph Type
Response Time (minutes)
15
10
5
0
linear−first
triangular−first
Graph Order
Graph Type
linear
triangular

Interaction of GRAPH and SCENARIO



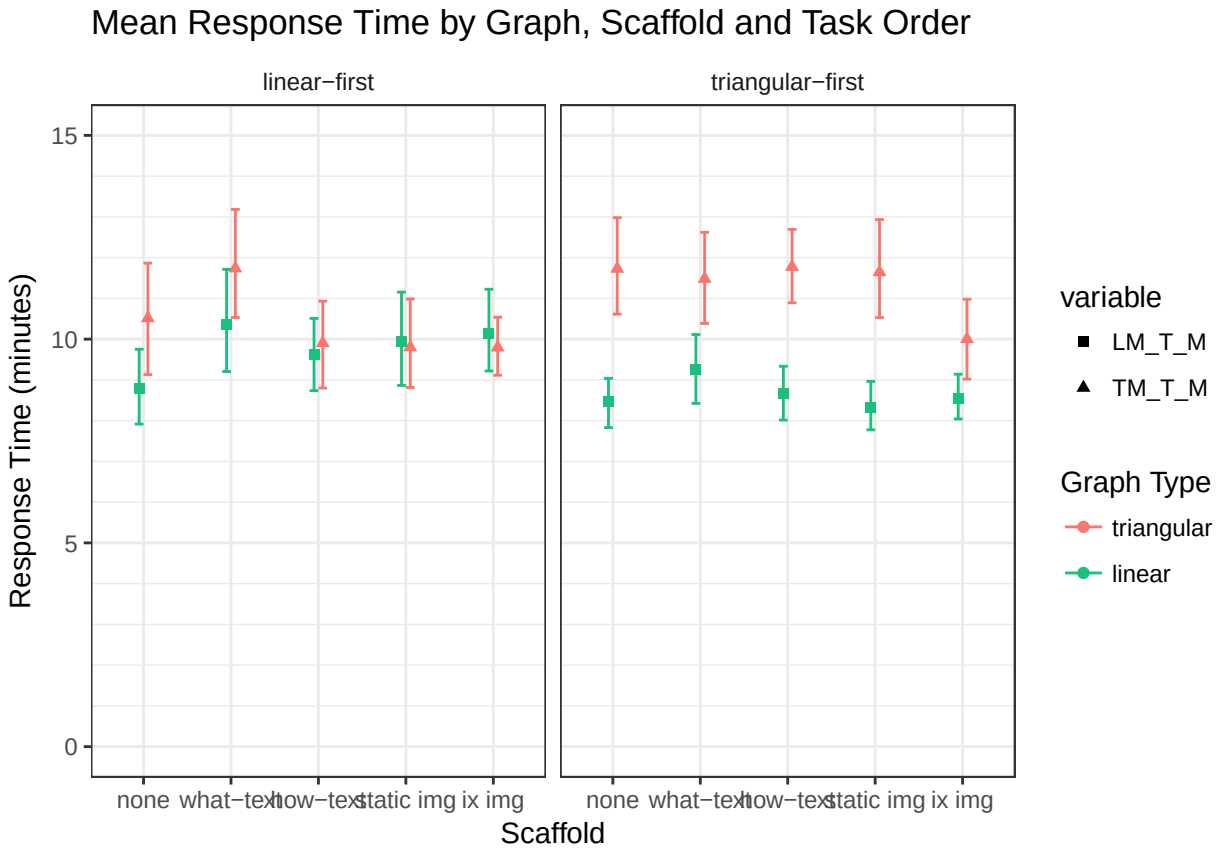
There was a significant interaction between graph-type and scenario

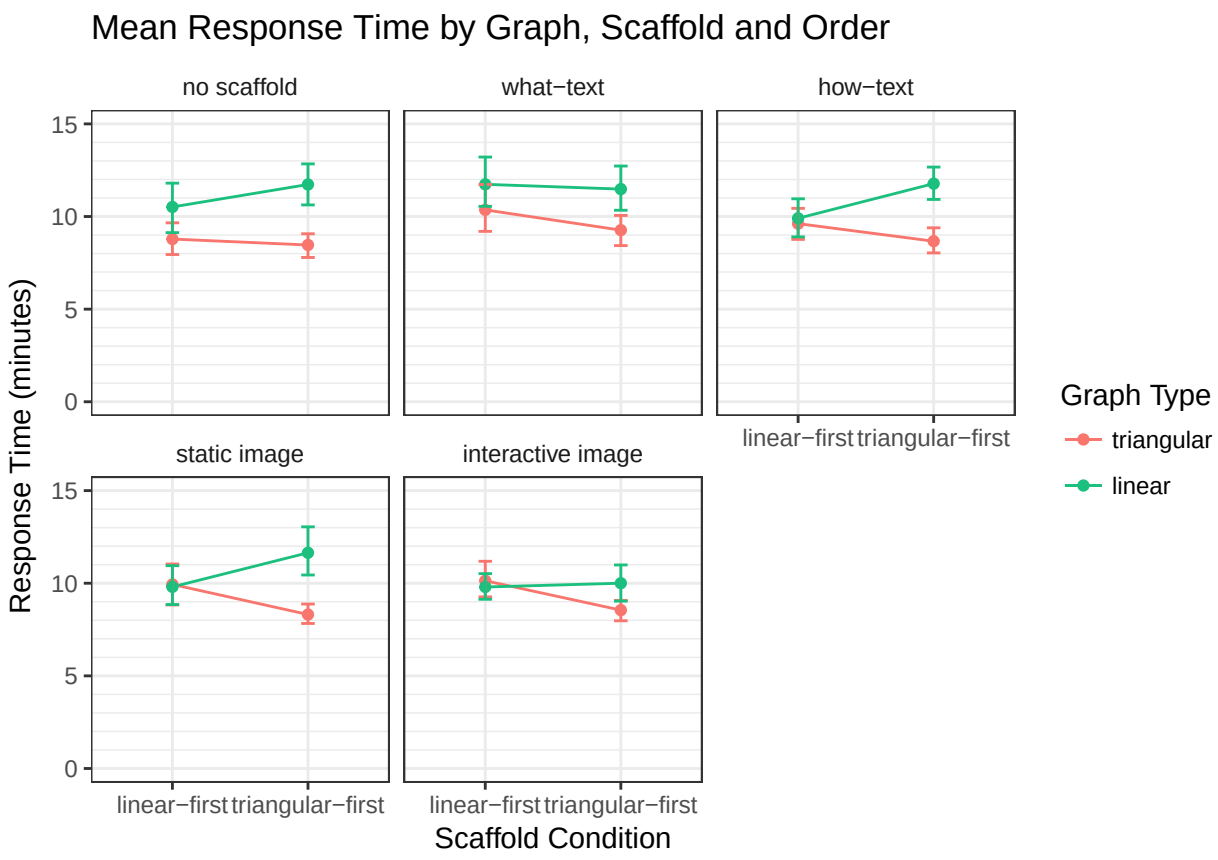




`IXN Graph Type & Order & Scenario` The three-way interaction of graph-type, scaffold condition and

graph-order approached significance at $F(4,297) = 2.23$, $p = 0.06$.





DV: DRAWING SCORE

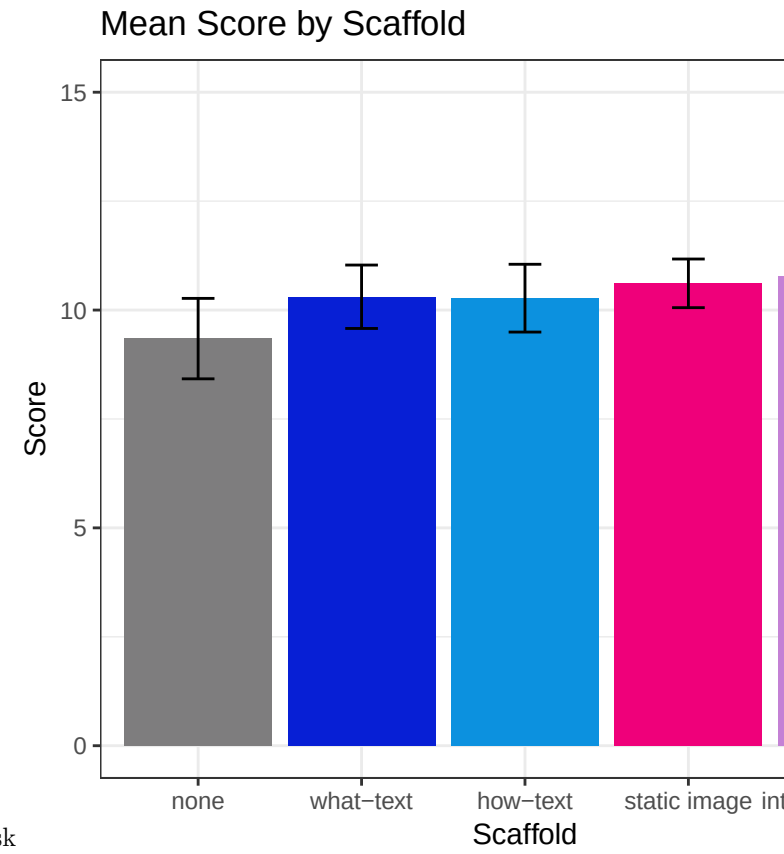
Construct a mixed effects ANOVA on DRAW SCORE

There is a signifant main effect of scaffold on drawing score, $F(4) = 2.44$, $p < 0.05$

```
##                                Df Sum Sq Mean Sq F value  Pr(>F)
## condition                       4   76.8   19.19   2.443 0.04681 *
## order                           1    0.1    0.06   0.007 0.93269
## lm_scenarios                    1   86.3   86.28  10.986 0.00103 **
## condition:order                 4   45.5   11.39   1.450 0.21762
## condition:lm_scenarios          4   33.7    8.41   1.071 0.37085
## order:lm_scenarios              1    8.6    8.56   1.090 0.29723
## condition:order:lm_scenarios    4    3.5    0.89   0.113 0.97801
## Residuals                     297 2332.7    7.85
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

There is a signifant main effect of scaffold on drawing score, $F(4) = 2.44$, $p < 0.05$

Main Effect: SCAFFOLD



Control group performed significantly worse on drawing task

DV: DRAWING TIME

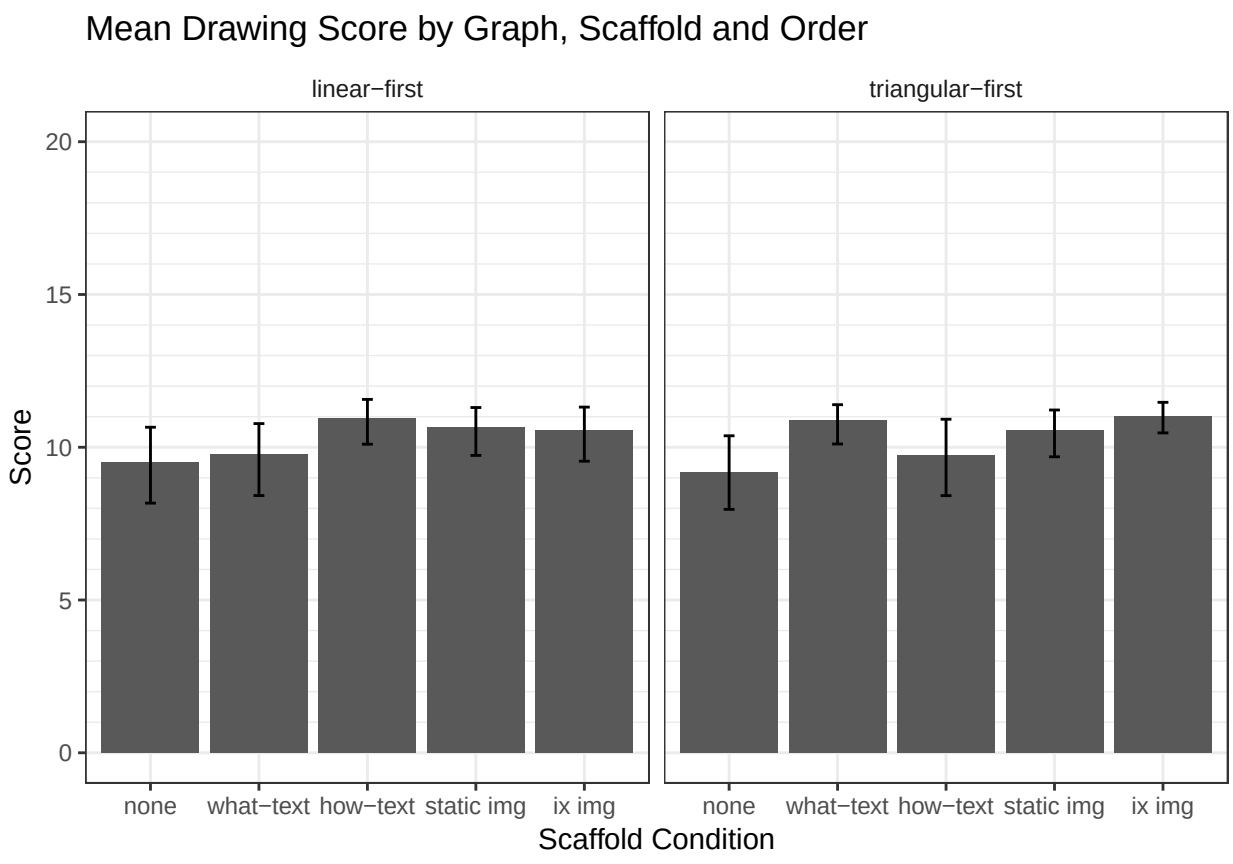
Construct a mixed effects ANOVA on DRAW TIME

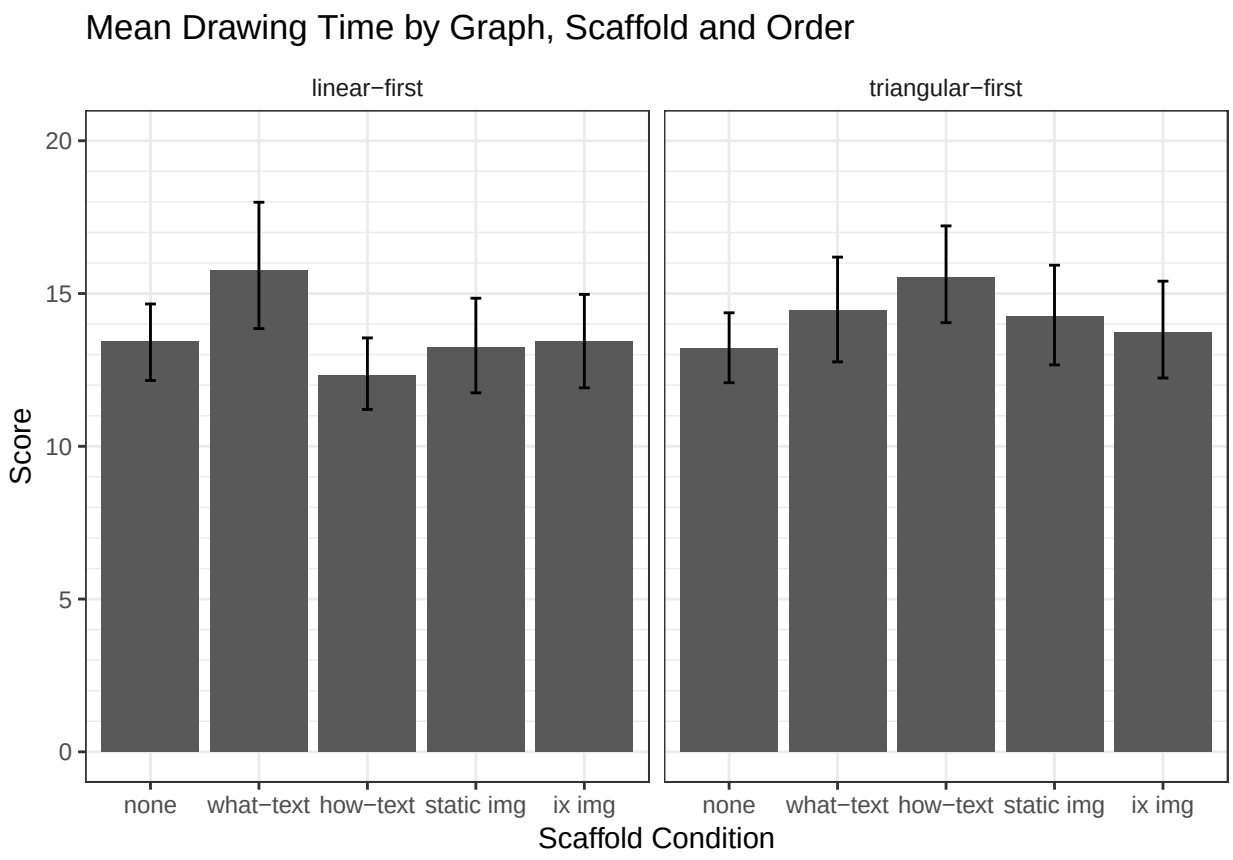
There wre no significant effects on drawing time

```
##                                Df Sum Sq Mean Sq F value Pr(>F)
## condition                       4    120   29.94   1.450 0.2176
## order                           1     32   32.10   1.554 0.2135
## lm_scenarios                    1      8    7.51   0.364 0.5470
## condition:order                 4    182   45.53   2.205 0.0685 .
## condition:lm_scenarios          4    100   25.08   1.215 0.3047
## order:lm_scenarios              1      5    5.13   0.248 0.6185
## condition:order:lm_scenarios    4     84   20.88   1.011 0.4019
## Residuals                     297   6134   20.65
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
##
## Call:
## aov(formula = value ~ condition * order * lm_scenarios, data = l_draw_t)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -8.5390 -2.8862 -0.7616  2.2737 15.7289
##
## Coefficients:
```

```
##                                 Estimate Std. Error t value Pr(>|t|)
## (Intercept)                      13.9502     0.2587  53.914   <2e-16 ***
## condition1                       -0.6710     0.5216  -1.286   0.1994
## condition2                        1.0357     0.5360   1.932   0.0543 .
## condition3                       -0.0184     0.5062  -0.036   0.9710
## condition4                       -0.1881     0.5172  -0.364   0.7163
## order1                           -0.3524     0.2587  -1.362   0.1743
## lm_scenarios1                     0.1623     0.2587   0.627   0.5310
## condition1:order1                 0.5271     0.5216   1.010   0.3131
## condition2:order1                 0.8501     0.5360   1.586   0.1138
## condition3:order1                -1.2550     0.5062  -2.479   0.0137 *
## condition4:order1                -0.1453     0.5172  -0.281   0.7790
## condition1:lm_scenarios1         -0.9051     0.5216  -1.735   0.0838 .
## condition2:lm_scenarios1         -0.2610     0.5360  -0.487   0.6267
## condition3:lm_scenarios1          0.0315     0.5062   0.062   0.9504
## condition4:lm_scenarios1          0.4181     0.5172   0.809   0.4194
## order1:lm_scenarios1             -0.1396     0.2587  -0.539   0.5900
## condition1:order1:lm_scenarios1   0.7647     0.5216   1.466   0.1437
## condition2:order1:lm_scenarios1  -0.7072     0.5360  -1.319   0.1881
## condition3:order1:lm_scenarios1   0.4314     0.5062   0.852   0.3948
## condition4:order1:lm_scenarios1  -0.2009     0.5172  -0.388   0.6979
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 4.544 on 297 degrees of freedom
## Multiple R-squared:  0.0796, Adjusted R-squared:  0.02072
## F-statistic: 1.352 on 19 and 297 DF,  p-value: 0.1499
```





Drawing Interpretation

DV: DRAW MODEL

Draw Model by Scaffold

The distribution of models by scaffold was non-random, $X(20) = 38.5$, $p < 0.01$

```
## Warning in chisq.test(tbl): Chi-squared approximation may be incorrect
```

```
##
##  Pearson's Chi-squared test
##
## data:  tbl
## X-squared = 38.533, df = 20, p-value = 0.007617
```

CONDITION

MODEL

0

1

2

3

4

All

Triangular (right angle)

17

6

9

10

2

44

Triangular

34

50

48

40

57

229

Linear Model

6

0

3

7

1

17

Scatterplot

1

0

1

0

1

3

Other

0

0

0

1

1

2

Triangular (asymmetric)

3

3

5

4

7

22

All

61

59

66

62

69

317

Draw Model by Task Order

The distribution of models by order was non-random, $X(5) = 14.4$, $p < 0.05$

```
## Warning in chisq.test(tbl): Chi-squared approximation may be incorrect

Pearson's Chi-squared test
```

data: tbl X-squared = 14.435, df = 5, p-value = 0.01307

ORDER

MODEL

LMFirst

TMFirst

All

Triangular (right angle)

21

23

44

Triangular

121

108

229

Linear Model

3

14

17

Scatterplot

0

3

3

Other

2

0

2

Triangular (asymmetric)

8

14

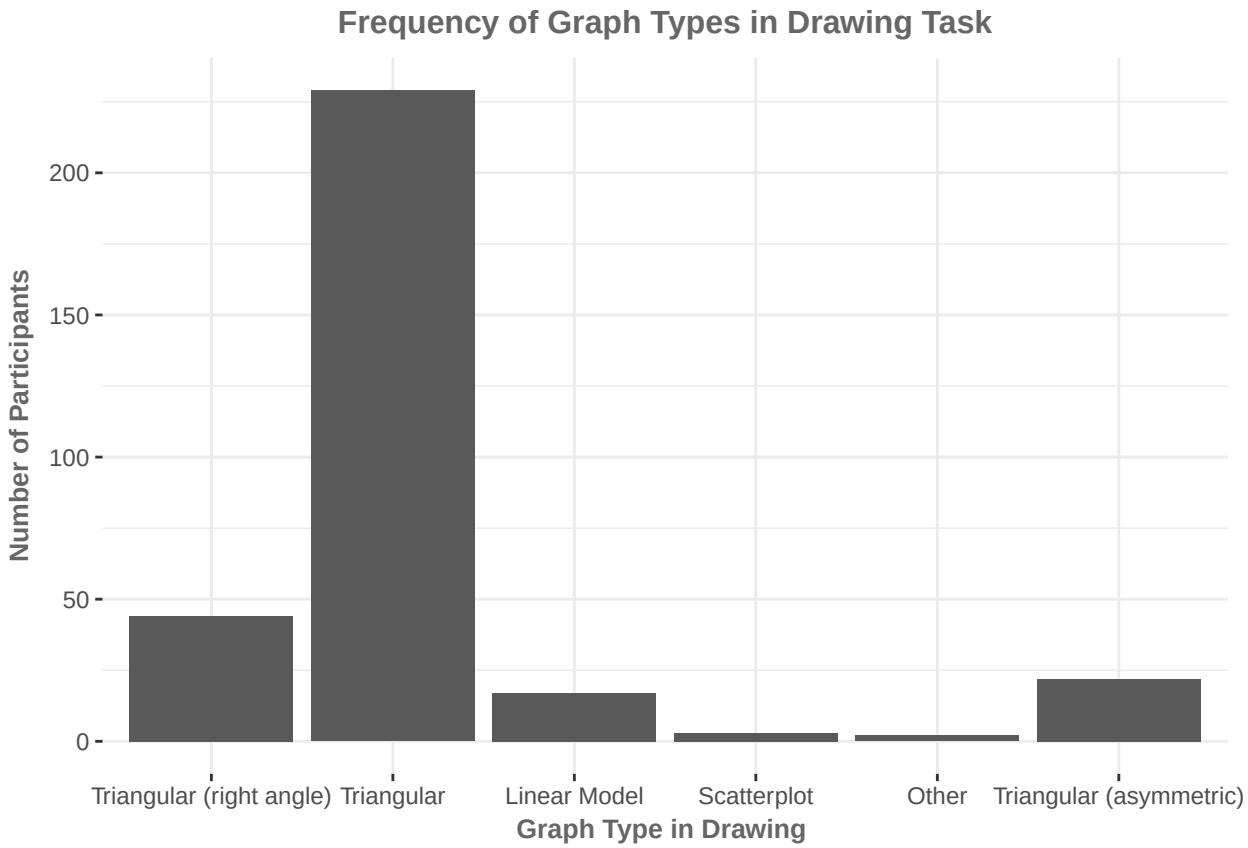
22

All

155

162

317


Frequency of Graph Types in Drawing Task
Number of Participants
200
150
100
50
0
Triangular (right angle)
Triangular
Linear Model
Scatterplot
Other
Triangular (asymmetric)
Graph Type in Drawing