Testing the hypothesis that something important happened

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PSY 653 Module 11 Lab
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Goals for this activity:

1) Practice identifying minimum effects for rejecting specific hypotheses
2) Using the sleep hygiene data, conduct regular and Bayesian ANOVAs to determine whether gender and occupation are related to mental health
    a) Interpret and compare results from the two analytic approaches

Though not shown in the demo, remember that it’s best practice to examine descriptives and visualize your data before conducting analyses :)

Part 1: Minimum effects practice

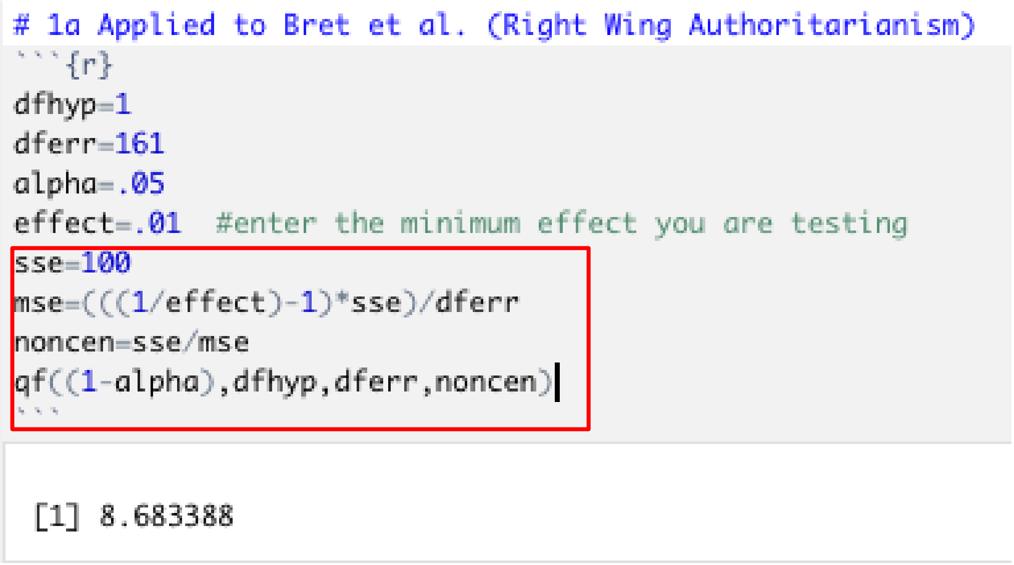
Minimum Effects Testing (MET)

- It tests the hypothesis that the effect of treatments falls somewhere in an interval between zero and some number

- Rather than testing if an effect is precisely zero, we can test if it falls above a range of values (The minimum effect you are testing)

The authors used Right Wing Authoritarianism (RWA) to predict differences in response time to in-group and out-group faces, and found a squared correlation of .07, which was significant, with F(1,161) = 4.81

Identifying minimum effects: Kevin’s minimum effects code



~~~~
# 1a Applied to Bret et al. (Right Wing Authoritarianism)
```{r}
dfhyp=1
dferr=161
alpha=.05
effect=.01  #enter the minimum effect you are testing
sse=100
mse=(((1/effect)-1)*sse)/dferr
noncen=sse/mse
qf((1-alpha),dfhyp,dferr,noncen)
```
~~~~

```
[1] 8.683388
```

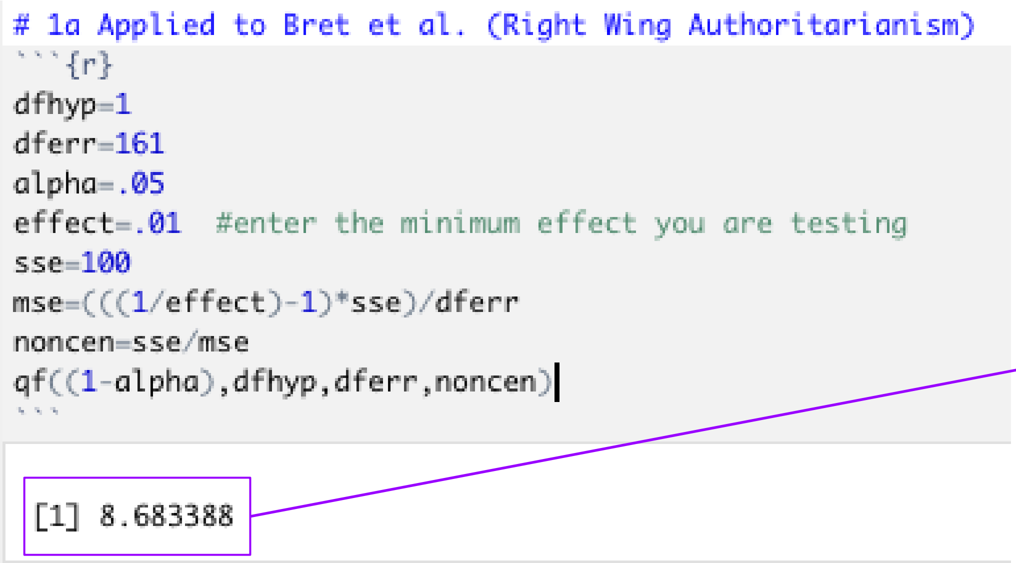
F(**1**,**161**) = 4.81,

α = **.05**,

Minimum effect = **1%**

Don’t change

Detecting minimum effects: Kevin’s minimum effects code



~~~
# 1a Applied to Bret et al. (Right Wing Authoritarianism)
```{r}
dfhyp=1
dferr=161
alpha=.05
effect=.01  #enter the minimum effect you are testing
sse=100
mse=(((1/effect)-1)*sse)/dferr
noncen=sse/mse
qf((1-alpha),dfhyp,dferr,noncen)
~~~

[1] 8.683388
```

F(1,161) = **4.81**

Compare the resulting minimum F-value needed to test an effect of 1% or more to the obtained F-value.
In this case we did NOT reach the threshold F-value to have a significant effect at 1%. The authors need an F-value of 8.68 to obtain a significant effect at a minimum effect of 1%.
```

# Identifying minimum effects via Murphy, Myors & Woloch (2014) “One Stop” F-table (Appendix B)

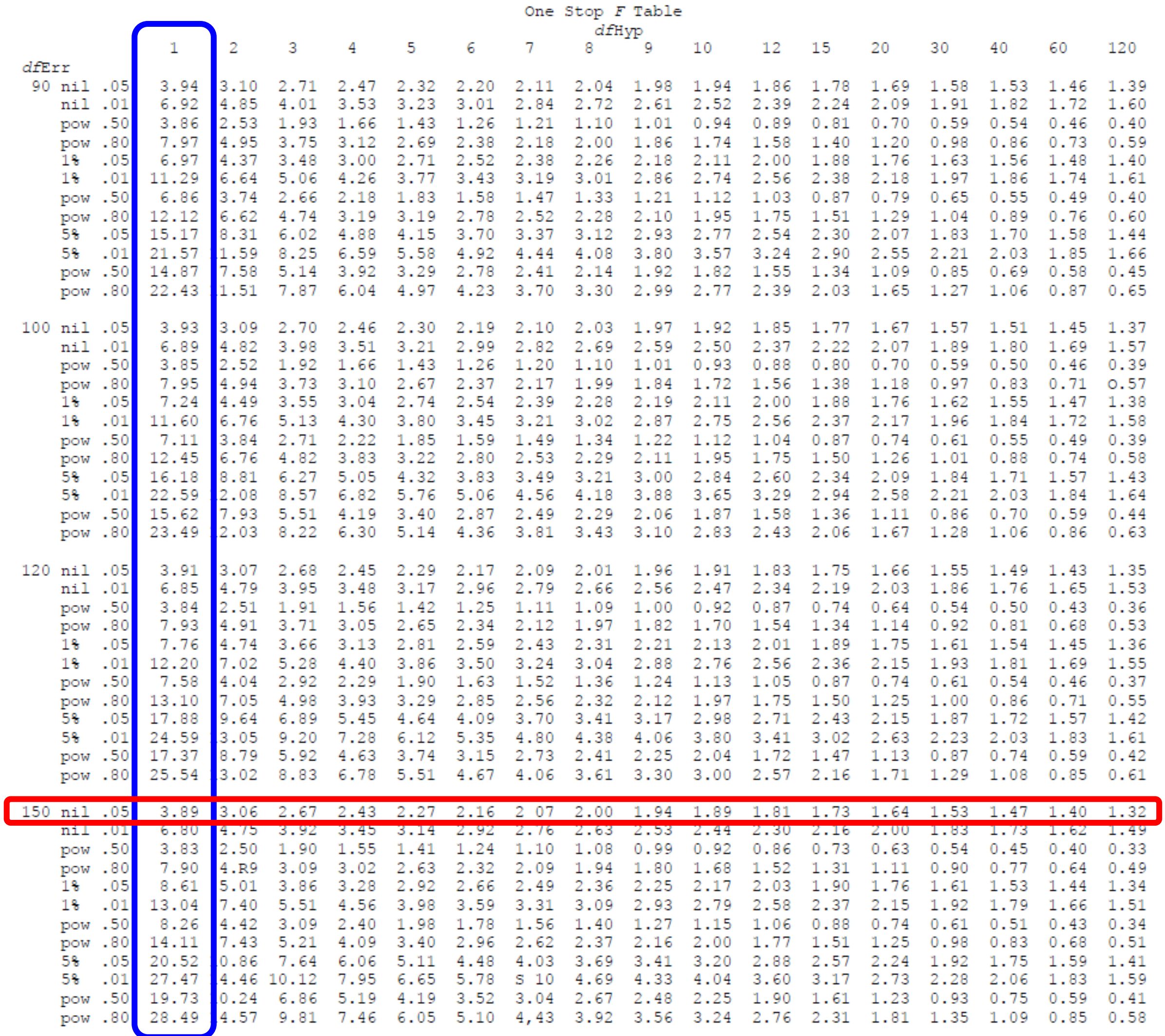
# Minimum F required (Appendix B)

## Comparison to a Nil effect

With a $DF_{hyp} = 1$ and $DF_{err} = 161$, the Authors need an F-value of 3.89 or more to obtain a significant effect.

**Obtained F = 4.81**

**We have a significant effect**



One Stop *F* Table

*df*Hyp

| *df*Err | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 15 | 20 | 30 | 40 | 60 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 90 | nil | .05 | 3.94 | 3.10 | 2.71 | 2.47 | 2.32 | 2.20 | 2.11 | 2.04 | 1.98 | 1.94 | 1.86 | 1.78 | 1.69 | 1.58 | 1.53 | 1.46 | 1.39 |
| | nil | .01 | 6.92 | 4.85 | 4.01 | 3.53 | 3.23 | 3.01 | 2.84 | 2.72 | 2.61 | 2.52 | 2.39 | 2.24 | 2.09 | 1.91 | 1.82 | 1.72 | 1.60 |
| | pow | .50 | 3.86 | 2.53 | 1.93 | 1.66 | 1.43 | 1.26 | 1.21 | 1.10 | 1.01 | 0.94 | 0.89 | 0.81 | 0.70 | 0.59 | 0.54 | 0.46 | 0.40 |
| | pow | .80 | 7.97 | 4.95 | 3.75 | 3.12 | 2.69 | 2.38 | 2.18 | 2.00 | 1.86 | 1.74 | 1.58 | 1.40 | 1.20 | 0.98 | 0.86 | 0.73 | 0.59 |
| | 1% | .05 | 6.97 | 4.37 | 3.48 | 3.00 | 2.71 | 2.52 | 2.38 | 2.26 | 2.18 | 2.11 | 2.00 | 1.88 | 1.76 | 1.63 | 1.56 | 1.48 | 1.40 |
| | 1% | .01 | 11.29 | 6.64 | 5.06 | 4.26 | 3.77 | 3.43 | 3.19 | 3.01 | 2.86 | 2.74 | 2.56 | 2.38 | 2.18 | 1.97 | 1.86 | 1.74 | 1.61 |
| | pow | .50 | 6.86 | 3.74 | 2.66 | 2.18 | 1.83 | 1.58 | 1.47 | 1.33 | 1.21 | 1.12 | 1.03 | 0.87 | 0.79 | 0.65 | 0.55 | 0.49 | 0.40 |
| | pow | .80 | 12.12 | 6.62 | 4.74 | 3.19 | 3.19 | 2.78 | 2.52 | 2.28 | 2.10 | 1.95 | 1.75 | 1.51 | 1.29 | 1.04 | 0.89 | 0.76 | 0.60 |
| | 5% | .05 | 15.17 | 8.31 | 6.02 | 4.88 | 4.15 | 3.70 | 3.37 | 3.12 | 2.93 | 2.77 | 2.54 | 2.30 | 2.07 | 1.83 | 1.70 | 1.58 | 1.44 |
| | 5% | .01 | 21.57 | 1.59 | 8.25 | 6.59 | 5.58 | 4.92 | 4.44 | 4.08 | 3.80 | 3.57 | 3.24 | 2.90 | 2.55 | 2.21 | 2.03 | 1.85 | 1.66 |
| | pow | .50 | 14.87 | 7.58 | 5.14 | 3.92 | 3.29 | 2.78 | 2.41 | 2.14 | 1.92 | 1.82 | 1.55 | 1.34 | 1.09 | 0.85 | 0.69 | 0.58 | 0.45 |
| | pow | .80 | 22.43 | 1.51 | 7.87 | 6.04 | 4.97 | 4.23 | 3.70 | 3.30 | 2.99 | 2.77 | 2.39 | 2.03 | 1.65 | 1.27 | 1.06 | 0.87 | 0.65 |
| 100 | nil | .05 | 3.93 | 3.09 | 2.70 | 2.46 | 2.30 | 2.19 | 2.10 | 2.03 | 1.97 | 1.92 | 1.85 | 1.77 | 1.67 | 1.57 | 1.51 | 1.45 | 1.37 |
| | nil | .01 | 6.89 | 4.82 | 3.98 | 3.51 | 3.21 | 2.99 | 2.82 | 2.69 | 2.59 | 2.50 | 2.37 | 2.22 | 2.07 | 1.89 | 1.80 | 1.69 | 1.57 |
| | pow | .50 | 3.85 | 2.52 | 1.92 | 1.66 | 1.43 | 1.26 | 1.20 | 1.10 | 1.01 | 0.93 | 0.88 | 0.80 | 0.70 | 0.59 | 0.50 | 0.46 | 0.39 |
| | pow | .80 | 7.95 | 4.94 | 3.73 | 3.10 | 2.67 | 2.37 | 2.17 | 1.99 | 1.84 | 1.72 | 1.56 | 1.38 | 1.18 | 0.97 | 0.83 | 0.71 | o.57 |
| | 1% | .05 | 7.24 | 4.49 | 3.55 | 3.04 | 2.74 | 2.54 | 2.39 | 2.28 | 2.19 | 2.11 | 2.00 | 1.88 | 1.76 | 1.62 | 1.55 | 1.47 | 1.38 |
| | 1% | .01 | 11.60 | 6.76 | 5.13 | 4.30 | 3.80 | 3.45 | 3.21 | 3.02 | 2.87 | 2.75 | 2.56 | 2.37 | 2.17 | 1.96 | 1.84 | 1.72 | 1.58 |
| | pow | .50 | 7.11 | 3.84 | 2.71 | 2.22 | 1.85 | 1.59 | 1.49 | 1.34 | 1.22 | 1.12 | 1.04 | 0.87 | 0.74 | 0.61 | 0.55 | 0.49 | 0.39 |
| | pow | .80 | 12.45 | 6.76 | 4.82 | 3.83 | 3.22 | 2.80 | 2.53 | 2.29 | 2.11 | 1.95 | 1.75 | 1.50 | 1.26 | 1.01 | 0.88 | 0.74 | 0.58 |
| | 5% | .05 | 16.18 | 8.81 | 6.27 | 5.05 | 4.32 | 3.83 | 3.49 | 3.21 | 3.00 | 2.84 | 2.60 | 2.34 | 2.09 | 1.84 | 1.71 | 1.57 | 1.43 |
| | 5% | .01 | 22.59 | 2.08 | 8.57 | 6.82 | 5.76 | 5.06 | 4.56 | 4.18 | 3.88 | 3.65 | 3.29 | 2.94 | 2.58 | 2.21 | 2.03 | 1.84 | 1.64 |
| | pow | .50 | 15.62 | 7.93 | 5.51 | 4.19 | 3.40 | 2.87 | 2.49 | 2.29 | 2.06 | 1.87 | 1.58 | 1.36 | 1.11 | 0.86 | 0.70 | 0.59 | 0.44 |
| | pow | .80 | 23.49 | 2.03 | 8.22 | 6.30 | 5.14 | 4.36 | 3.81 | 3.43 | 3.10 | 2.83 | 2.43 | 2.06 | 1.67 | 1.28 | 1.06 | 0.86 | 0.63 |
| 120 | nil | .05 | 3.91 | 3.07 | 2.68 | 2.45 | 2.29 | 2.17 | 2.09 | 2.01 | 1.96 | 1.91 | 1.83 | 1.75 | 1.66 | 1.55 | 1.49 | 1.43 | 1.35 |
| | nil | .01 | 6.85 | 4.79 | 3.95 | 3.48 | 3.17 | 2.96 | 2.79 | 2.66 | 2.56 | 2.47 | 2.34 | 2.19 | 2.03 | 1.86 | 1.76 | 1.65 | 1.53 |
| | pow | .50 | 3.84 | 2.51 | 1.91 | 1.56 | 1.42 | 1.25 | 1.11 | 1.09 | 1.00 | 0.92 | 0.87 | 0.74 | 0.64 | 0.54 | 0.50 | 0.43 | 0.36 |
| | pow | .80 | 7.93 | 4.91 | 3.71 | 3.05 | 2.65 | 2.34 | 2.12 | 1.97 | 1.82 | 1.70 | 1.54 | 1.34 | 1.14 | 0.92 | 0.81 | 0.68 | 0.53 |
| | 1% | .05 | 7.76 | 4.74 | 3.66 | 3.13 | 2.81 | 2.59 | 2.43 | 2.31 | 2.21 | 2.13 | 2.01 | 1.89 | 1.75 | 1.61 | 1.54 | 1.45 | 1.36 |
| | 1% | .01 | 12.20 | 7.02 | 5.28 | 4.40 | 3.86 | 3.50 | 3.24 | 3.04 | 2.88 | 2.76 | 2.56 | 2.36 | 2.15 | 1.93 | 1.81 | 1.69 | 1.55 |
| | pow | .50 | 7.58 | 4.04 | 2.92 | 2.29 | 1.90 | 1.63 | 1.52 | 1.36 | 1.24 | 1.13 | 1.05 | 0.87 | 0.74 | 0.61 | 0.54 | 0.46 | 0.37 |
| | pow | .80 | 13.10 | 7.05 | 4.98 | 3.93 | 3.29 | 2.85 | 2.56 | 2.32 | 2.12 | 1.97 | 1.75 | 1.50 | 1.25 | 1.00 | 0.86 | 0.71 | 0.55 |
| | 5% | .05 | 17.88 | 9.64 | 6.89 | 5.45 | 4.64 | 4.09 | 3.70 | 3.41 | 3.17 | 2.98 | 2.71 | 2.43 | 2.15 | 1.87 | 1.72 | 1.57 | 1.42 |
| | 5% | .01 | 24.59 | 3.05 | 9.20 | 7.28 | 6.12 | 5.35 | 4.80 | 4.38 | 4.06 | 3.80 | 3.41 | 3.02 | 2.63 | 2.23 | 2.03 | 1.83 | 1.61 |
| | pow | .50 | 17.37 | 8.79 | 5.92 | 4.63 | 3.74 | 3.15 | 2.73 | 2.41 | 2.25 | 2.04 | 1.72 | 1.47 | 1.13 | 0.87 | 0.74 | 0.59 | 0.42 |
| | pow | .80 | 25.54 | 3.02 | 8.83 | 6.78 | 5.51 | 4.67 | 4.06 | 3.61 | 3.30 | 3.00 | 2.57 | 2.16 | 1.71 | 1.29 | 1.08 | 0.85 | 0.61 |
| 150 | nil | .05 | 3.89 | 3.06 | 2.67 | 2.43 | 2.27 | 2.16 | 2 07 | 2.00 | 1.94 | 1.89 | 1.81 | 1.73 | 1.64 | 1.53 | 1.47 | 1.40 | 1.32 |
| | nil | .01 | 6.80 | 4.75 | 3.92 | 3.45 | 3.14 | 2.92 | 2.76 | 2.63 | 2.53 | 2.44 | 2.30 | 2.16 | 2.00 | 1.83 | 1.73 | 1.62 | 1.49 |
| | pow | .50 | 3.83 | 2.50 | 1.90 | 1.55 | 1.41 | 1.24 | 1.10 | 1.08 | 0.99 | 0.92 | 0.86 | 0.73 | 0.63 | 0.54 | 0.45 | 0.40 | 0.33 |
| | pow | .80 | 7.90 | 4.R9 | 3.09 | 3.02 | 2.63 | 2.32 | 2.09 | 1.94 | 1.80 | 1.68 | 1.52 | 1.31 | 1.11 | 0.90 | 0.77 | 0.64 | 0.49 |
| | 1% | .05 | 8.61 | 5.01 | 3.86 | 3.28 | 2.92 | 2.66 | 2.49 | 2.36 | 2.25 | 2.17 | 2.03 | 1.90 | 1.76 | 1.61 | 1.53 | 1.44 | 1.34 |
| | 1% | .01 | 13.04 | 7.40 | 5.51 | 4.56 | 3.98 | 3.59 | 3.31 | 3.09 | 2.93 | 2.79 | 2.58 | 2.37 | 2.15 | 1.92 | 1.79 | 1.66 | 1.51 |
| | pow | .50 | 8.26 | 4.42 | 3.09 | 2.40 | 1.98 | 1.78 | 1.56 | 1.40 | 1.27 | 1.15 | 1.06 | 0.88 | 0.74 | 0.61 | 0.51 | 0.43 | 0.34 |
| | pow | .80 | 14.11 | 7.43 | 5.21 | 4.09 | 3.40 | 2.96 | 2.62 | 2.37 | 2.16 | 2.00 | 1.77 | 1.51 | 1.25 | 0.98 | 0.83 | 0.68 | 0.51 |
| | 5% | .05 | 20.52 | 0.86 | 7.64 | 6.06 | 5.11 | 4.48 | 4.03 | 3.69 | 3.41 | 3.20 | 2.88 | 2.57 | 2.24 | 1.92 | 1.75 | 1.59 | 1.41 |
| | 5% | .01 | 27.47 | 4.46 | 10.12 | 7.95 | 6.65 | 5.78 | s 10 | 4.69 | 4.33 | 4.04 | 3.60 | 3.17 | 2.73 | 2.28 | 2.06 | 1.83 | 1.59 |
| | pow | .50 | 19.73 | 0.24 | 6.86 | 5.19 | 4.19 | 3.52 | 3.04 | 2.67 | 2.48 | 2.25 | 1.90 | 1.61 | 1.23 | 0.93 | 0.75 | 0.59 | 0.41 |
| | pow | .80 | 28.49 | 4.57 | 9.81 | 7.46 | 6.05 | 5.10 | 4,43 | 3.92 | 3.56 | 3.24 | 2.76 | 2.31 | 1.81 | 1.35 | 1.09 | 0.85 | 0.58 |

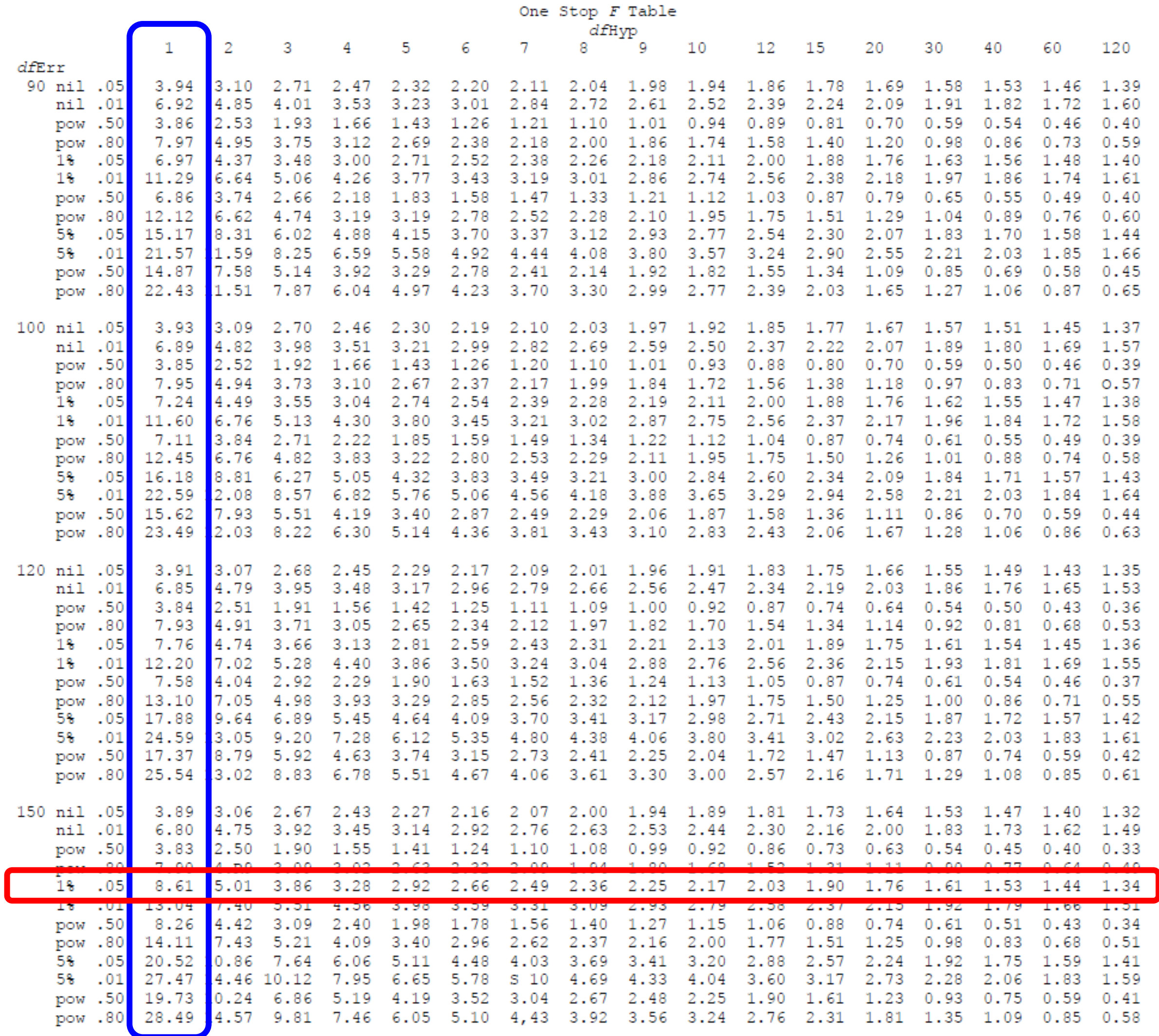
# Minimum F required (Appendix B)

## Comparison to a 1% effect

With a $DF_{hyp}$ = 1 and $DF_{err}$ = 161, the Authors need an F-value of 8.61 or more to obtain a significant effect.

**Obtained F = 4.81**

**We do NOT have a significant effect**



One Stop *F* Table

*dfHyp*

| *dfErr* | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 15 | 20 | 30 | 40 | 60 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 90 | nil | .05 | 3.94 | 3.10 | 2.71 | 2.47 | 2.32 | 2.20 | 2.11 | 2.04 | 1.98 | 1.94 | 1.86 | 1.78 | 1.69 | 1.58 | 1.53 | 1.46 | 1.39 |
| | nil | .01 | 6.92 | 4.85 | 4.01 | 3.53 | 3.23 | 3.01 | 2.84 | 2.72 | 2.61 | 2.52 | 2.39 | 2.24 | 2.09 | 1.91 | 1.82 | 1.72 | 1.60 |
| | pow | .50 | 3.86 | 2.53 | 1.93 | 1.66 | 1.43 | 1.26 | 1.21 | 1.10 | 1.01 | 0.94 | 0.89 | 0.81 | 0.70 | 0.59 | 0.54 | 0.46 | 0.40 |
| | pow | .80 | 7.97 | 4.95 | 3.75 | 3.12 | 2.69 | 2.38 | 2.18 | 2.00 | 1.86 | 1.74 | 1.58 | 1.40 | 1.20 | 0.98 | 0.86 | 0.73 | 0.59 |
| | 1% | .05 | 6.97 | 4.37 | 3.48 | 3.00 | 2.71 | 2.52 | 2.38 | 2.26 | 2.18 | 2.11 | 2.00 | 1.88 | 1.76 | 1.63 | 1.56 | 1.48 | 1.40 |
| | 1% | .01 | 11.29 | 6.64 | 5.06 | 4.26 | 3.77 | 3.43 | 3.19 | 3.01 | 2.86 | 2.74 | 2.56 | 2.38 | 2.18 | 1.97 | 1.86 | 1.74 | 1.61 |
| | pow | .50 | 6.86 | 3.74 | 2.66 | 2.18 | 1.83 | 1.58 | 1.47 | 1.33 | 1.21 | 1.12 | 1.03 | 0.87 | 0.79 | 0.65 | 0.55 | 0.49 | 0.40 |
| | pow | .80 | 12.12 | 6.62 | 4.74 | 3.19 | 3.19 | 2.78 | 2.52 | 2.28 | 2.10 | 1.95 | 1.75 | 1.51 | 1.29 | 1.04 | 0.89 | 0.76 | 0.60 |
| | 5% | .05 | 15.17 | 8.31 | 6.02 | 4.88 | 4.15 | 3.70 | 3.37 | 3.12 | 2.93 | 2.77 | 2.54 | 2.30 | 2.07 | 1.83 | 1.70 | 1.58 | 1.44 |
| | 5% | .01 | 21.57 | 1.59 | 8.25 | 6.59 | 5.58 | 4.92 | 4.44 | 4.08 | 3.80 | 3.57 | 3.24 | 2.90 | 2.55 | 2.21 | 2.03 | 1.85 | 1.66 |
| | pow | .50 | 14.87 | 7.58 | 5.14 | 3.92 | 3.29 | 2.78 | 2.41 | 2.14 | 1.92 | 1.82 | 1.55 | 1.34 | 1.09 | 0.85 | 0.69 | 0.58 | 0.45 |
| | pow | .80 | 22.43 | 1.51 | 7.87 | 6.04 | 4.97 | 4.23 | 3.70 | 3.30 | 2.99 | 2.77 | 2.39 | 2.03 | 1.65 | 1.27 | 1.06 | 0.87 | 0.65 |
| 100 | nil | .05 | 3.93 | 3.09 | 2.70 | 2.46 | 2.30 | 2.19 | 2.10 | 2.03 | 1.97 | 1.92 | 1.85 | 1.77 | 1.67 | 1.57 | 1.51 | 1.45 | 1.37 |
| | nil | .01 | 6.89 | 4.82 | 3.98 | 3.51 | 3.21 | 2.99 | 2.82 | 2.69 | 2.59 | 2.50 | 2.37 | 2.22 | 2.07 | 1.89 | 1.80 | 1.69 | 1.57 |
| | pow | .50 | 3.85 | 2.52 | 1.92 | 1.66 | 1.43 | 1.26 | 1.20 | 1.10 | 1.01 | 0.93 | 0.88 | 0.80 | 0.70 | 0.59 | 0.50 | 0.46 | 0.39 |
| | pow | .80 | 7.95 | 4.94 | 3.73 | 3.10 | 2.67 | 2.37 | 2.17 | 1.99 | 1.84 | 1.72 | 1.56 | 1.38 | 1.18 | 0.97 | 0.83 | 0.71 | 0.57 |
| | 1% | .05 | 7.24 | 4.49 | 3.55 | 3.04 | 2.74 | 2.54 | 2.39 | 2.28 | 2.19 | 2.11 | 2.00 | 1.88 | 1.76 | 1.62 | 1.55 | 1.47 | 1.38 |
| | 1% | .01 | 11.60 | 6.76 | 5.13 | 4.30 | 3.80 | 3.45 | 3.21 | 3.02 | 2.87 | 2.75 | 2.56 | 2.37 | 2.17 | 1.96 | 1.84 | 1.72 | 1.58 |
| | pow | .50 | 7.11 | 3.84 | 2.71 | 2.22 | 1.85 | 1.59 | 1.49 | 1.34 | 1.22 | 1.12 | 1.04 | 0.87 | 0.74 | 0.61 | 0.55 | 0.49 | 0.39 |
| | pow | .80 | 12.45 | 6.76 | 4.82 | 3.83 | 3.22 | 2.80 | 2.53 | 2.29 | 2.11 | 1.95 | 1.75 | 1.50 | 1.26 | 1.01 | 0.88 | 0.74 | 0.58 |
| | 5% | .05 | 16.18 | 8.81 | 6.27 | 5.05 | 4.32 | 3.83 | 3.49 | 3.21 | 3.00 | 2.84 | 2.60 | 2.34 | 2.09 | 1.84 | 1.71 | 1.57 | 1.43 |
| | 5% | .01 | 22.59 | 2.08 | 8.57 | 6.82 | 5.76 | 5.06 | 4.56 | 4.18 | 3.88 | 3.65 | 3.29 | 2.94 | 2.58 | 2.21 | 2.03 | 1.84 | 1.64 |
| | pow | .50 | 15.62 | 7.93 | 5.51 | 4.19 | 3.40 | 2.87 | 2.49 | 2.29 | 2.06 | 1.87 | 1.58 | 1.36 | 1.11 | 0.86 | 0.70 | 0.59 | 0.44 |
| | pow | .80 | 23.49 | 2.03 | 8.22 | 6.30 | 5.14 | 4.36 | 3.81 | 3.43 | 3.10 | 2.83 | 2.43 | 2.06 | 1.67 | 1.28 | 1.06 | 0.86 | 0.63 |
| 120 | nil | .05 | 3.91 | 3.07 | 2.68 | 2.45 | 2.29 | 2.17 | 2.09 | 2.01 | 1.96 | 1.91 | 1.83 | 1.75 | 1.66 | 1.55 | 1.49 | 1.43 | 1.35 |
| | nil | .01 | 6.85 | 4.79 | 3.95 | 3.48 | 3.17 | 2.96 | 2.79 | 2.66 | 2.56 | 2.47 | 2.34 | 2.19 | 2.03 | 1.86 | 1.76 | 1.65 | 1.53 |
| | pow | .50 | 3.84 | 2.51 | 1.91 | 1.56 | 1.42 | 1.25 | 1.11 | 1.09 | 1.00 | 0.92 | 0.87 | 0.74 | 0.64 | 0.54 | 0.50 | 0.43 | 0.36 |
| | pow | .80 | 7.93 | 4.91 | 3.71 | 3.05 | 2.65 | 2.34 | 2.12 | 1.97 | 1.82 | 1.70 | 1.54 | 1.34 | 1.14 | 0.92 | 0.81 | 0.68 | 0.53 |
| | 1% | .05 | 7.76 | 4.74 | 3.66 | 3.13 | 2.81 | 2.59 | 2.43 | 2.31 | 2.21 | 2.13 | 2.01 | 1.89 | 1.75 | 1.61 | 1.54 | 1.45 | 1.36 |
| | 1% | .01 | 12.20 | 7.02 | 5.28 | 4.40 | 3.86 | 3.50 | 3.24 | 3.04 | 2.88 | 2.76 | 2.56 | 2.36 | 2.15 | 1.93 | 1.81 | 1.69 | 1.55 |
| | pow | .50 | 7.58 | 4.04 | 2.92 | 2.29 | 1.90 | 1.63 | 1.52 | 1.36 | 1.24 | 1.13 | 1.05 | 0.87 | 0.74 | 0.61 | 0.54 | 0.46 | 0.37 |
| | pow | .80 | 13.10 | 7.05 | 4.98 | 3.93 | 3.29 | 2.85 | 2.56 | 2.32 | 2.12 | 1.97 | 1.75 | 1.50 | 1.25 | 1.00 | 0.86 | 0.71 | 0.55 |
| | 5% | .05 | 17.88 | 9.64 | 6.89 | 5.45 | 4.64 | 4.09 | 3.70 | 3.41 | 3.17 | 2.98 | 2.71 | 2.43 | 2.15 | 1.87 | 1.72 | 1.57 | 1.42 |
| | 5% | .01 | 24.59 | 3.05 | 9.20 | 7.28 | 6.12 | 5.35 | 4.80 | 4.38 | 4.06 | 3.80 | 3.41 | 3.02 | 2.63 | 2.23 | 2.03 | 1.83 | 1.61 |
| | pow | .50 | 17.37 | 8.79 | 5.92 | 4.63 | 3.74 | 3.15 | 2.73 | 2.41 | 2.25 | 2.04 | 1.72 | 1.47 | 1.13 | 0.87 | 0.74 | 0.59 | 0.42 |
| | pow | .80 | 25.54 | 3.02 | 8.83 | 6.78 | 5.51 | 4.67 | 4.06 | 3.61 | 3.30 | 3.00 | 2.57 | 2.16 | 1.71 | 1.29 | 1.08 | 0.85 | 0.61 |
| 150 | nil | .05 | 3.89 | 3.06 | 2.67 | 2.43 | 2.27 | 2.16 | 2 07 | 2.00 | 1.94 | 1.89 | 1.81 | 1.73 | 1.64 | 1.53 | 1.47 | 1.40 | 1.32 |
| | nil | .01 | 6.80 | 4.75 | 3.92 | 3.45 | 3.14 | 2.92 | 2.76 | 2.63 | 2.53 | 2.44 | 2.30 | 2.16 | 2.00 | 1.83 | 1.73 | 1.62 | 1.49 |
| | pow | .50 | 3.83 | 2.50 | 1.90 | 1.55 | 1.41 | 1.24 | 1.10 | 1.08 | 0.99 | 0.92 | 0.86 | 0.73 | 0.63 | 0.54 | 0.45 | 0.40 | 0.33 |
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | 1% | .05 | 8.61 | 5.01 | 3.86 | 3.28 | 2.92 | 2.66 | 2.49 | 2.36 | 2.25 | 2.17 | 2.03 | 1.90 | 1.76 | 1.61 | 1.53 | 1.44 | 1.34 |
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | pow | .50 | 8.26 | 4.42 | 3.09 | 2.40 | 1.98 | 1.78 | 1.56 | 1.40 | 1.27 | 1.15 | 1.06 | 0.88 | 0.74 | 0.61 | 0.51 | 0.43 | 0.34 |
| | pow | .80 | 14.11 | 7.43 | 5.21 | 4.09 | 3.40 | 2.96 | 2.62 | 2.37 | 2.16 | 2.00 | 1.77 | 1.51 | 1.25 | 0.98 | 0.83 | 0.68 | 0.51 |
| | 5% | .05 | 20.52 | 0.86 | 7.64 | 6.06 | 5.11 | 4.48 | 4.03 | 3.69 | 3.41 | 3.20 | 2.88 | 2.57 | 2.24 | 1.92 | 1.75 | 1.59 | 1.41 |
| | 5% | .01 | 27.47 | 4.46 | 10.12 | 7.95 | 6.65 | 5.78 | s 10 | 4.69 | 4.33 | 4.04 | 3.60 | 3.17 | 2.73 | 2.28 | 2.06 | 1.83 | 1.59 |
| | pow | .50 | 19.73 | 0.24 | 6.86 | 5.19 | 4.19 | 3.52 | 3.04 | 2.67 | 2.48 | 2.25 | 1.90 | 1.61 | 1.23 | 0.93 | 0.75 | 0.59 | 0.41 |
| | pow | .80 | 28.49 | 4.57 | 9.81 | 7.46 | 6.05 | 5.10 | 4,43 | 3.92 | 3.56 | 3.24 | 2.76 | 2.31 | 1.81 | 1.35 | 1.09 | 0.85 | 0.58 |

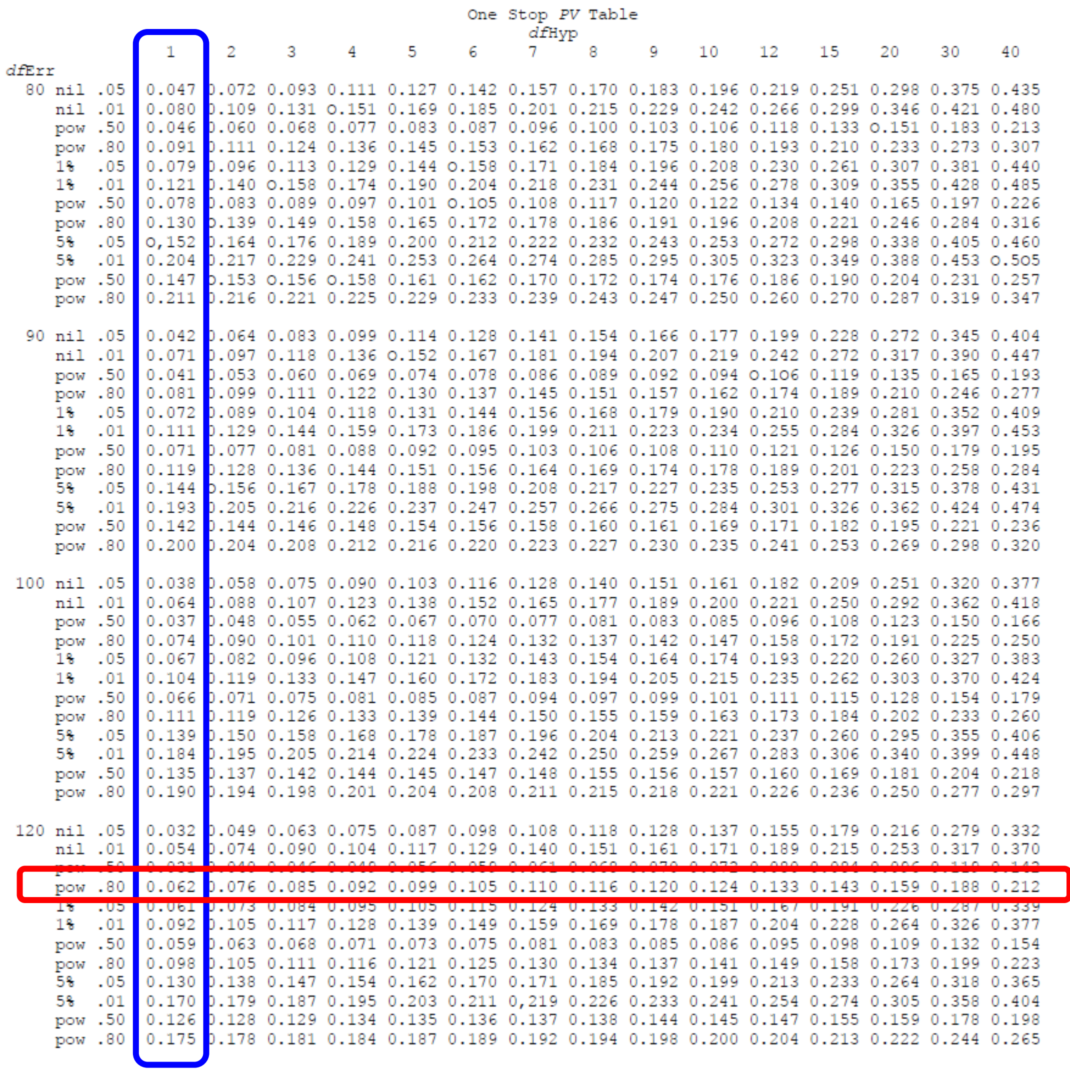
# Identifying minimum sample size via Murphy, Myors & Woloch (2014) “One Stop” PV-table (Appendix C)

# Minimum sample size needed (Appendix C)

## Comparison to a Nil effect

The authors need a minimum sample size of 122 to have power of .80 with the effect they obtained.

**Obtained $R^2 = .07$**



One Stop *PV* Table

*df*Hyp

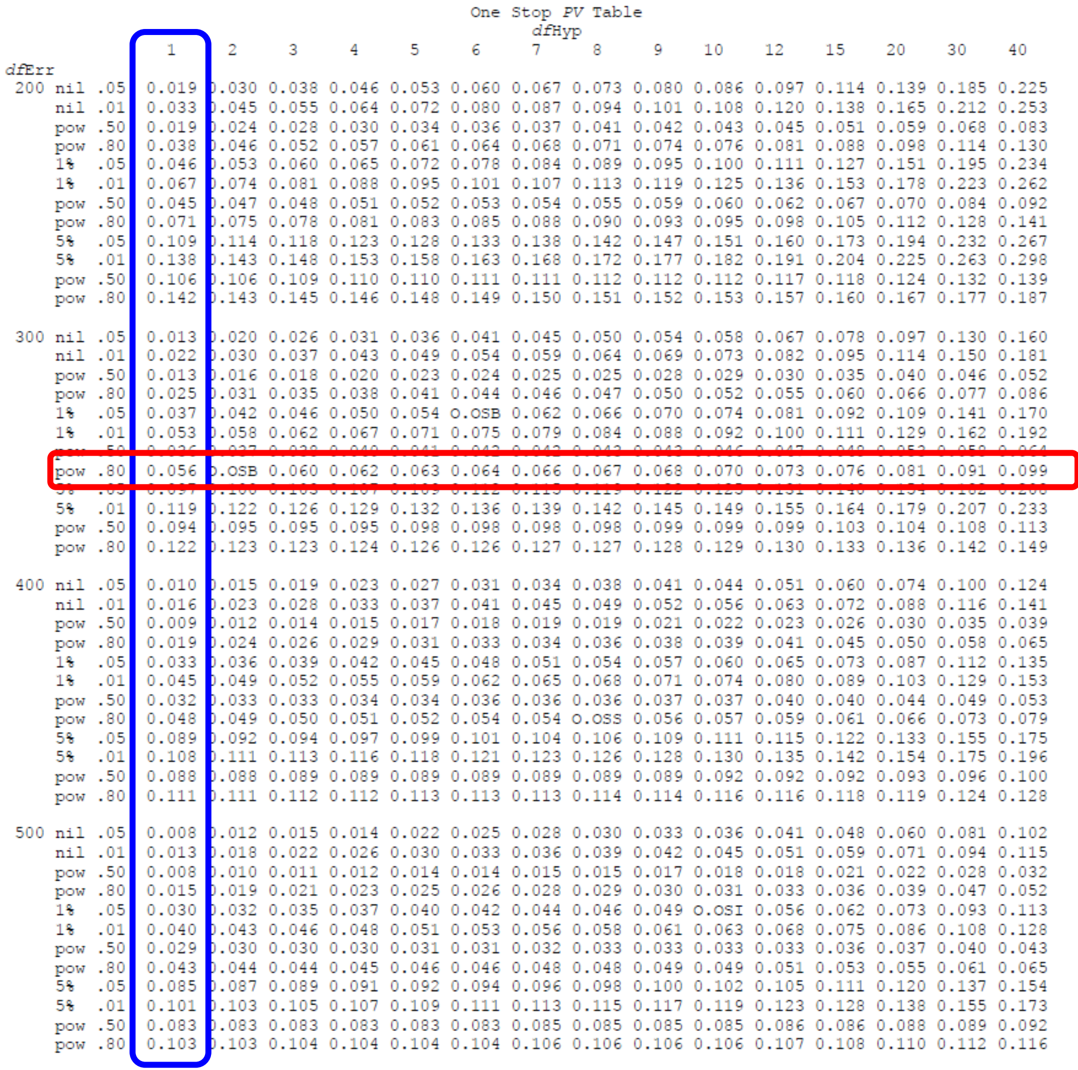
| *df*Err | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 15 | 20 | 30 | 40 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 80 | nil | .05 | 0.047 | 0.072 | 0.093 | 0.111 | 0.127 | 0.142 | 0.157 | 0.170 | 0.183 | 0.196 | 0.219 | 0.251 | 0.298 | 0.375 | 0.435 |
| | nil | .01 | 0.080 | 0.109 | 0.131 | 0.151 | 0.169 | 0.185 | 0.201 | 0.215 | 0.229 | 0.242 | 0.266 | 0.299 | 0.346 | 0.421 | 0.480 |
| | pow | .50 | 0.046 | 0.060 | 0.068 | 0.077 | 0.083 | 0.087 | 0.096 | 0.100 | 0.103 | 0.106 | 0.118 | 0.133 | 0.151 | 0.183 | 0.213 |
| | pow | .80 | 0.091 | 0.111 | 0.124 | 0.136 | 0.145 | 0.153 | 0.162 | 0.168 | 0.175 | 0.180 | 0.193 | 0.210 | 0.233 | 0.273 | 0.307 |
| | 1% | .05 | 0.079 | 0.096 | 0.113 | 0.129 | 0.144 | 0.158 | 0.171 | 0.184 | 0.196 | 0.208 | 0.230 | 0.261 | 0.307 | 0.381 | 0.440 |
| | 1% | .01 | 0.121 | 0.140 | 0.158 | 0.174 | 0.190 | 0.204 | 0.218 | 0.231 | 0.244 | 0.256 | 0.278 | 0.309 | 0.355 | 0.428 | 0.485 |
| | pow | .50 | 0.078 | 0.083 | 0.089 | 0.097 | 0.101 | 0.105 | 0.108 | 0.117 | 0.120 | 0.122 | 0.134 | 0.140 | 0.165 | 0.197 | 0.226 |
| | pow | .80 | 0.130 | 0.139 | 0.149 | 0.158 | 0.165 | 0.172 | 0.178 | 0.186 | 0.191 | 0.196 | 0.208 | 0.221 | 0.246 | 0.284 | 0.316 |
| | 5% | .05 | 0,152 | 0.164 | 0.176 | 0.189 | 0.200 | 0.212 | 0.222 | 0.232 | 0.243 | 0.253 | 0.272 | 0.298 | 0.338 | 0.405 | 0.460 |
| | 5% | .01 | 0.204 | 0.217 | 0.229 | 0.241 | 0.253 | 0.264 | 0.274 | 0.285 | 0.295 | 0.305 | 0.323 | 0.349 | 0.388 | 0.453 | 0.505 |
| | pow | .50 | 0.147 | 0.153 | 0.156 | 0.158 | 0.161 | 0.162 | 0.170 | 0.172 | 0.174 | 0.176 | 0.186 | 0.190 | 0.204 | 0.231 | 0.257 |
| | pow | .80 | 0.211 | 0.216 | 0.221 | 0.225 | 0.229 | 0.233 | 0.239 | 0.243 | 0.247 | 0.250 | 0.260 | 0.270 | 0.287 | 0.319 | 0.347 |
| 90 | nil | .05 | 0.042 | 0.064 | 0.083 | 0.099 | 0.114 | 0.128 | 0.141 | 0.154 | 0.166 | 0.177 | 0.199 | 0.228 | 0.272 | 0.345 | 0.404 |
| | nil | .01 | 0.071 | 0.097 | 0.118 | 0.136 | 0.152 | 0.167 | 0.181 | 0.194 | 0.207 | 0.219 | 0.242 | 0.272 | 0.317 | 0.390 | 0.447 |
| | pow | .50 | 0.041 | 0.053 | 0.060 | 0.069 | 0.074 | 0.078 | 0.086 | 0.089 | 0.092 | 0.094 | 0.106 | 0.119 | 0.135 | 0.165 | 0.193 |
| | pow | .80 | 0.081 | 0.099 | 0.111 | 0.122 | 0.130 | 0.137 | 0.145 | 0.151 | 0.157 | 0.162 | 0.174 | 0.189 | 0.210 | 0.246 | 0.277 |
| | 1% | .05 | 0.072 | 0.089 | 0.104 | 0.118 | 0.131 | 0.144 | 0.156 | 0.168 | 0.179 | 0.190 | 0.210 | 0.239 | 0.281 | 0.352 | 0.409 |
| | 1% | .01 | 0.111 | 0.129 | 0.144 | 0.159 | 0.173 | 0.186 | 0.199 | 0.211 | 0.223 | 0.234 | 0.255 | 0.284 | 0.326 | 0.397 | 0.453 |
| | pow | .50 | 0.071 | 0.077 | 0.081 | 0.088 | 0.092 | 0.095 | 0.103 | 0.106 | 0.108 | 0.110 | 0.121 | 0.126 | 0.150 | 0.179 | 0.195 |
| | pow | .80 | 0.119 | 0.128 | 0.136 | 0.144 | 0.151 | 0.156 | 0.164 | 0.169 | 0.174 | 0.178 | 0.189 | 0.201 | 0.223 | 0.258 | 0.284 |
| | 5% | .05 | 0.144 | 0.156 | 0.167 | 0.178 | 0.188 | 0.198 | 0.208 | 0.217 | 0.227 | 0.235 | 0.253 | 0.277 | 0.315 | 0.378 | 0.431 |
| | 5% | .01 | 0.193 | 0.205 | 0.216 | 0.226 | 0.237 | 0.247 | 0.257 | 0.266 | 0.275 | 0.284 | 0.301 | 0.326 | 0.362 | 0.424 | 0.474 |
| | pow | .50 | 0.142 | 0.144 | 0.146 | 0.148 | 0.154 | 0.156 | 0.158 | 0.160 | 0.161 | 0.169 | 0.171 | 0.182 | 0.195 | 0.221 | 0.236 |
| | pow | .80 | 0.200 | 0.204 | 0.208 | 0.212 | 0.216 | 0.220 | 0.223 | 0.227 | 0.230 | 0.235 | 0.241 | 0.253 | 0.269 | 0.298 | 0.320 |
| 100 | nil | .05 | 0.038 | 0.058 | 0.075 | 0.090 | 0.103 | 0.116 | 0.128 | 0.140 | 0.151 | 0.161 | 0.182 | 0.209 | 0.251 | 0.320 | 0.377 |
| | nil | .01 | 0.064 | 0.088 | 0.107 | 0.123 | 0.138 | 0.152 | 0.165 | 0.177 | 0.189 | 0.200 | 0.221 | 0.250 | 0.292 | 0.362 | 0.418 |
| | pow | .50 | 0.037 | 0.048 | 0.055 | 0.062 | 0.067 | 0.070 | 0.077 | 0.081 | 0.083 | 0.085 | 0.096 | 0.108 | 0.123 | 0.150 | 0.166 |
| | pow | .80 | 0.074 | 0.090 | 0.101 | 0.110 | 0.118 | 0.124 | 0.132 | 0.137 | 0.142 | 0.147 | 0.158 | 0.172 | 0.191 | 0.225 | 0.250 |
| | 1% | .05 | 0.067 | 0.082 | 0.096 | 0.108 | 0.121 | 0.132 | 0.143 | 0.154 | 0.164 | 0.174 | 0.193 | 0.220 | 0.260 | 0.327 | 0.383 |
| | 1% | .01 | 0.104 | 0.119 | 0.133 | 0.147 | 0.160 | 0.172 | 0.183 | 0.194 | 0.205 | 0.215 | 0.235 | 0.262 | 0.303 | 0.370 | 0.424 |
| | pow | .50 | 0.066 | 0.071 | 0.075 | 0.081 | 0.085 | 0.087 | 0.094 | 0.097 | 0.099 | 0.101 | 0.111 | 0.115 | 0.128 | 0.154 | 0.179 |
| | pow | .80 | 0.111 | 0.119 | 0.126 | 0.133 | 0.139 | 0.144 | 0.150 | 0.155 | 0.159 | 0.163 | 0.173 | 0.184 | 0.202 | 0.233 | 0.260 |
| | 5% | .05 | 0.139 | 0.150 | 0.158 | 0.168 | 0.178 | 0.187 | 0.196 | 0.204 | 0.213 | 0.221 | 0.237 | 0.260 | 0.295 | 0.355 | 0.406 |
| | 5% | .01 | 0.184 | 0.195 | 0.205 | 0.214 | 0.224 | 0.233 | 0.242 | 0.250 | 0.259 | 0.267 | 0.283 | 0.306 | 0.340 | 0.399 | 0.448 |
| | pow | .50 | 0.135 | 0.137 | 0.142 | 0.144 | 0.145 | 0.147 | 0.148 | 0.155 | 0.156 | 0.157 | 0.160 | 0.169 | 0.181 | 0.204 | 0.218 |
| | pow | .80 | 0.190 | 0.194 | 0.198 | 0.201 | 0.204 | 0.208 | 0.211 | 0.215 | 0.218 | 0.221 | 0.226 | 0.236 | 0.250 | 0.277 | 0.297 |
| 120 | nil | .05 | 0.032 | 0.049 | 0.063 | 0.075 | 0.087 | 0.098 | 0.108 | 0.118 | 0.128 | 0.137 | 0.155 | 0.179 | 0.216 | 0.279 | 0.332 |
| | nil | .01 | 0.054 | 0.074 | 0.090 | 0.104 | 0.117 | 0.129 | 0.140 | 0.151 | 0.161 | 0.171 | 0.189 | 0.215 | 0.253 | 0.317 | 0.370 |
| | pow | .50 | 0.031 | 0.040 | 0.046 | 0.049 | 0.056 | 0.059 | 0.061 | 0.068 | 0.070 | 0.072 | 0.080 | 0.084 | 0.096 | 0.110 | 0.142 |
| | pow | .80 | 0.062 | 0.076 | 0.085 | 0.092 | 0.099 | 0.105 | 0.110 | 0.116 | 0.120 | 0.124 | 0.133 | 0.143 | 0.159 | 0.188 | 0.212 |
| | 1% | .05 | 0.061 | 0.073 | 0.084 | 0.095 | 0.105 | 0.115 | 0.124 | 0.133 | 0.142 | 0.151 | 0.167 | 0.191 | 0.226 | 0.287 | 0.339 |
| | 1% | .01 | 0.092 | 0.105 | 0.117 | 0.128 | 0.139 | 0.149 | 0.159 | 0.169 | 0.178 | 0.187 | 0.204 | 0.228 | 0.264 | 0.326 | 0.377 |
| | pow | .50 | 0.059 | 0.063 | 0.068 | 0.071 | 0.073 | 0.075 | 0.081 | 0.083 | 0.085 | 0.086 | 0.095 | 0.098 | 0.109 | 0.132 | 0.154 |
| | pow | .80 | 0.098 | 0.105 | 0.111 | 0.116 | 0.121 | 0.125 | 0.130 | 0.134 | 0.137 | 0.141 | 0.149 | 0.158 | 0.173 | 0.199 | 0.223 |
| | 5% | .05 | 0.130 | 0.138 | 0.147 | 0.154 | 0.162 | 0.170 | 0.171 | 0.185 | 0.192 | 0.199 | 0.213 | 0.233 | 0.264 | 0.318 | 0.365 |
| | 5% | .01 | 0.170 | 0.179 | 0.187 | 0.195 | 0.203 | 0.211 | 0,219 | 0.226 | 0.233 | 0.241 | 0.254 | 0.274 | 0.305 | 0.358 | 0.404 |
| | pow | .50 | 0.126 | 0.128 | 0.129 | 0.134 | 0.135 | 0.136 | 0.137 | 0.138 | 0.144 | 0.145 | 0.147 | 0.155 | 0.159 | 0.178 | 0.198 |
| | pow | .80 | 0.175 | 0.178 | 0.181 | 0.184 | 0.187 | 0.189 | 0.192 | 0.194 | 0.198 | 0.200 | 0.204 | 0.213 | 0.222 | 0.244 | 0.265 |

# Minimum sample size needed (Appendix C)

## Comparison to a 1% effect

The authors need a minimum sample size of 302 to have power of .80 with the effect they obtained.

**Obtained $R^2$ = .07**



One Stop *PV* Table

*df*Hyp

| *df*Err | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 15 | 20 | 30 | 40 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 200 | nil | .05 | 0.019 | 0.030 | 0.038 | 0.046 | 0.053 | 0.060 | 0.067 | 0.073 | 0.080 | 0.086 | 0.097 | 0.114 | 0.139 | 0.185 | 0.225 |
| | nil | .01 | 0.033 | 0.045 | 0.055 | 0.064 | 0.072 | 0.080 | 0.087 | 0.094 | 0.101 | 0.108 | 0.120 | 0.138 | 0.165 | 0.212 | 0.253 |
| | pow | .50 | 0.019 | 0.024 | 0.028 | 0.030 | 0.034 | 0.036 | 0.037 | 0.041 | 0.042 | 0.043 | 0.045 | 0.051 | 0.059 | 0.068 | 0.083 |
| | pow | .80 | 0.038 | 0.046 | 0.052 | 0.057 | 0.061 | 0.064 | 0.068 | 0.071 | 0.074 | 0.076 | 0.081 | 0.088 | 0.098 | 0.114 | 0.130 |
| | 1% | .05 | 0.046 | 0.053 | 0.060 | 0.065 | 0.072 | 0.078 | 0.084 | 0.089 | 0.095 | 0.100 | 0.111 | 0.127 | 0.151 | 0.195 | 0.234 |
| | 1% | .01 | 0.067 | 0.074 | 0.081 | 0.088 | 0.095 | 0.101 | 0.107 | 0.113 | 0.119 | 0.125 | 0.136 | 0.153 | 0.178 | 0.223 | 0.262 |
| | pow | .50 | 0.045 | 0.047 | 0.048 | 0.051 | 0.052 | 0.053 | 0.054 | 0.055 | 0.059 | 0.060 | 0.062 | 0.067 | 0.070 | 0.084 | 0.092 |
| | pow | .80 | 0.071 | 0.075 | 0.078 | 0.081 | 0.083 | 0.085 | 0.088 | 0.090 | 0.093 | 0.095 | 0.098 | 0.105 | 0.112 | 0.128 | 0.141 |
| | 5% | .05 | 0.109 | 0.114 | 0.118 | 0.123 | 0.128 | 0.133 | 0.138 | 0.142 | 0.147 | 0.151 | 0.160 | 0.173 | 0.194 | 0.232 | 0.267 |
| | 5% | .01 | 0.138 | 0.143 | 0.148 | 0.153 | 0.158 | 0.163 | 0.168 | 0.172 | 0.177 | 0.182 | 0.191 | 0.204 | 0.225 | 0.263 | 0.298 |
| | pow | .50 | 0.106 | 0.106 | 0.109 | 0.110 | 0.110 | 0.111 | 0.111 | 0.112 | 0.112 | 0.112 | 0.117 | 0.118 | 0.124 | 0.132 | 0.139 |
| | pow | .80 | 0.142 | 0.143 | 0.145 | 0.146 | 0.148 | 0.149 | 0.150 | 0.151 | 0.152 | 0.153 | 0.157 | 0.160 | 0.167 | 0.177 | 0.187 |
| 300 | nil | .05 | 0.013 | 0.020 | 0.026 | 0.031 | 0.036 | 0.041 | 0.045 | 0.050 | 0.054 | 0.058 | 0.067 | 0.078 | 0.097 | 0.130 | 0.160 |
| | nil | .01 | 0.022 | 0.030 | 0.037 | 0.043 | 0.049 | 0.054 | 0.059 | 0.064 | 0.069 | 0.073 | 0.082 | 0.095 | 0.114 | 0.150 | 0.181 |
| | pow | .50 | 0.013 | 0.016 | 0.018 | 0.020 | 0.023 | 0.024 | 0.025 | 0.025 | 0.028 | 0.029 | 0.030 | 0.035 | 0.040 | 0.046 | 0.052 |
| | pow | .80 | 0.025 | 0.031 | 0.035 | 0.038 | 0.041 | 0.044 | 0.046 | 0.047 | 0.050 | 0.052 | 0.055 | 0.060 | 0.066 | 0.077 | 0.086 |
| | 1% | .05 | 0.037 | 0.042 | 0.046 | 0.050 | 0.054 | O.OSB | 0.062 | 0.066 | 0.070 | 0.074 | 0.081 | 0.092 | 0.109 | 0.141 | 0.170 |
| | 1% | .01 | 0.053 | 0.058 | 0.062 | 0.067 | 0.071 | 0.075 | 0.079 | 0.084 | 0.088 | 0.092 | 0.100 | 0.111 | 0.129 | 0.162 | 0.192 |
| | pow | .50 | 0.036 | 0.037 | 0.039 | 0.040 | 0.041 | 0.042 | 0.043 | 0.043 | 0.043 | 0.046 | 0.047 | 0.049 | 0.053 | 0.058 | 0.064 |
| | pow | .80 | 0.056 | 0.OSB | 0.060 | 0.062 | 0.063 | 0.064 | 0.066 | 0.067 | 0.068 | 0.070 | 0.073 | 0.076 | 0.081 | 0.091 | 0.099 |
| | 5% | .05 | 0.097 | 0.100 | 0.103 | 0.107 | 0.109 | 0.112 | 0.115 | 0.119 | 0.122 | 0.125 | 0.131 | 0.140 | 0.154 | 0.182 | 0.208 |
| | 5% | .01 | 0.119 | 0.122 | 0.126 | 0.129 | 0.132 | 0.136 | 0.139 | 0.142 | 0.145 | 0.149 | 0.155 | 0.164 | 0.179 | 0.207 | 0.233 |
| | pow | .50 | 0.094 | 0.095 | 0.095 | 0.095 | 0.098 | 0.098 | 0.098 | 0.098 | 0.099 | 0.099 | 0.099 | 0.103 | 0.104 | 0.108 | 0.113 |
| | pow | .80 | 0.122 | 0.123 | 0.123 | 0.124 | 0.126 | 0.126 | 0.127 | 0.127 | 0.128 | 0.129 | 0.130 | 0.133 | 0.136 | 0.142 | 0.149 |
| 400 | nil | .05 | 0.010 | 0.015 | 0.019 | 0.023 | 0.027 | 0.031 | 0.034 | 0.038 | 0.041 | 0.044 | 0.051 | 0.060 | 0.074 | 0.100 | 0.124 |
| | nil | .01 | 0.016 | 0.023 | 0.028 | 0.033 | 0.037 | 0.041 | 0.045 | 0.049 | 0.052 | 0.056 | 0.063 | 0.072 | 0.088 | 0.116 | 0.141 |
| | pow | .50 | 0.009 | 0.012 | 0.014 | 0.015 | 0.017 | 0.018 | 0.019 | 0.019 | 0.021 | 0.022 | 0.023 | 0.026 | 0.030 | 0.035 | 0.039 |
| | pow | .80 | 0.019 | 0.024 | 0.026 | 0.029 | 0.031 | 0.033 | 0.034 | 0.036 | 0.038 | 0.039 | 0.041 | 0.045 | 0.050 | 0.058 | 0.065 |
| | 1% | .05 | 0.033 | 0.036 | 0.039 | 0.042 | 0.045 | 0.048 | 0.051 | 0.054 | 0.057 | 0.060 | 0.065 | 0.073 | 0.087 | 0.112 | 0.135 |
| | 1% | .01 | 0.045 | 0.049 | 0.052 | 0.055 | 0.059 | 0.062 | 0.065 | 0.068 | 0.071 | 0.074 | 0.080 | 0.089 | 0.103 | 0.129 | 0.153 |
| | pow | .50 | 0.032 | 0.033 | 0.033 | 0.034 | 0.034 | 0.036 | 0.036 | 0.036 | 0.037 | 0.037 | 0.040 | 0.040 | 0.044 | 0.049 | 0.053 |
| | pow | .80 | 0.048 | 0.049 | 0.050 | 0.051 | 0.052 | 0.054 | 0.054 | O.OSS | 0.056 | 0.057 | 0.059 | 0.061 | 0.066 | 0.073 | 0.079 |
| | 5% | .05 | 0.089 | 0.092 | 0.094 | 0.097 | 0.099 | 0.101 | 0.104 | 0.106 | 0.109 | 0.111 | 0.115 | 0.122 | 0.133 | 0.155 | 0.175 |
| | 5% | .01 | 0.108 | 0.111 | 0.113 | 0.116 | 0.118 | 0.121 | 0.123 | 0.126 | 0.128 | 0.130 | 0.135 | 0.142 | 0.154 | 0.175 | 0.196 |
| | pow | .50 | 0.088 | 0.088 | 0.089 | 0.089 | 0.089 | 0.089 | 0.089 | 0.089 | 0.089 | 0.092 | 0.092 | 0.092 | 0.093 | 0.096 | 0.100 |
| | pow | .80 | 0.111 | 0.111 | 0.112 | 0.112 | 0.113 | 0.113 | 0.113 | 0.114 | 0.114 | 0.116 | 0.116 | 0.118 | 0.119 | 0.124 | 0.128 |
| 500 | nil | .05 | 0.008 | 0.012 | 0.015 | 0.014 | 0.022 | 0.025 | 0.028 | 0.030 | 0.033 | 0.036 | 0.041 | 0.048 | 0.060 | 0.081 | 0.102 |
| | nil | .01 | 0.013 | 0.018 | 0.022 | 0.026 | 0.030 | 0.033 | 0.036 | 0.039 | 0.042 | 0.045 | 0.051 | 0.059 | 0.071 | 0.094 | 0.115 |
| | pow | .50 | 0.008 | 0.010 | 0.011 | 0.012 | 0.014 | 0.014 | 0.015 | 0.015 | 0.017 | 0.018 | 0.018 | 0.021 | 0.022 | 0.028 | 0.032 |
| | pow | .80 | 0.015 | 0.019 | 0.021 | 0.023 | 0.025 | 0.026 | 0.028 | 0.029 | 0.030 | 0.031 | 0.033 | 0.036 | 0.039 | 0.047 | 0.052 |
| | 1% | .05 | 0.030 | 0.032 | 0.035 | 0.037 | 0.040 | 0.042 | 0.044 | 0.046 | 0.049 | O.OSI | 0.056 | 0.062 | 0.073 | 0.093 | 0.113 |
| | 1% | .01 | 0.040 | 0.043 | 0.046 | 0.048 | 0.051 | 0.053 | 0.056 | 0.058 | 0.061 | 0.063 | 0.068 | 0.075 | 0.086 | 0.108 | 0.128 |
| | pow | .50 | 0.029 | 0.030 | 0.030 | 0.030 | 0.031 | 0.031 | 0.032 | 0.033 | 0.033 | 0.033 | 0.033 | 0.036 | 0.037 | 0.040 | 0.043 |
| | pow | .80 | 0.043 | 0.044 | 0.044 | 0.045 | 0.046 | 0.046 | 0.048 | 0.048 | 0.049 | 0.049 | 0.051 | 0.053 | 0.055 | 0.061 | 0.065 |
| | 5% | .05 | 0.085 | 0.087 | 0.089 | 0.091 | 0.092 | 0.094 | 0.096 | 0.098 | 0.100 | 0.102 | 0.105 | 0.111 | 0.120 | 0.137 | 0.154 |
| | 5% | .01 | 0.101 | 0.103 | 0.105 | 0.107 | 0.109 | 0.111 | 0.113 | 0.115 | 0.117 | 0.119 | 0.123 | 0.128 | 0.138 | 0.155 | 0.173 |
| | pow | .50 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.085 | 0.085 | 0.085 | 0.085 | 0.086 | 0.086 | 0.088 | 0.089 | 0.092 |
| | pow | .80 | 0.103 | 0.103 | 0.104 | 0.104 | 0.104 | 0.104 | 0.106 | 0.106 | 0.106 | 0.106 | 0.107 | 0.108 | 0.110 | 0.112 | 0.116 |

# Part 2: Practice with bayesian analyses

# A quick introduction to bayesian statistics

- Increasingly popular in psychology
- Allows us to make probabilistic statements about events/hypotheses (tells us the probability of specific events given the observed data included in the analysis)
- Models account for background knowledge *(not discussed in detail in this lab)*
- May allow us to overcome several limitations of NHSTs (e.g., the reproducibility crisis in psychology and reliance on large sample sizes)
- All common statistical analyses can be conducted in a bayesian framework (ANOVAs, regression, correlation, factor analysis, etc.)
- Interpretations are often more concrete than significance tests (clear probability statements)

Note: While bayesian analyses are on the rise and may overcome several limitations of frequentist methods, use of classical statistics has been argued for as well (e.g., this NY Times article from 2014: https://www.nytimes.com/2014/09/30/science/the-odds-continually-updated.html?_r=1)

# Compare bayesian and frequentist statistics

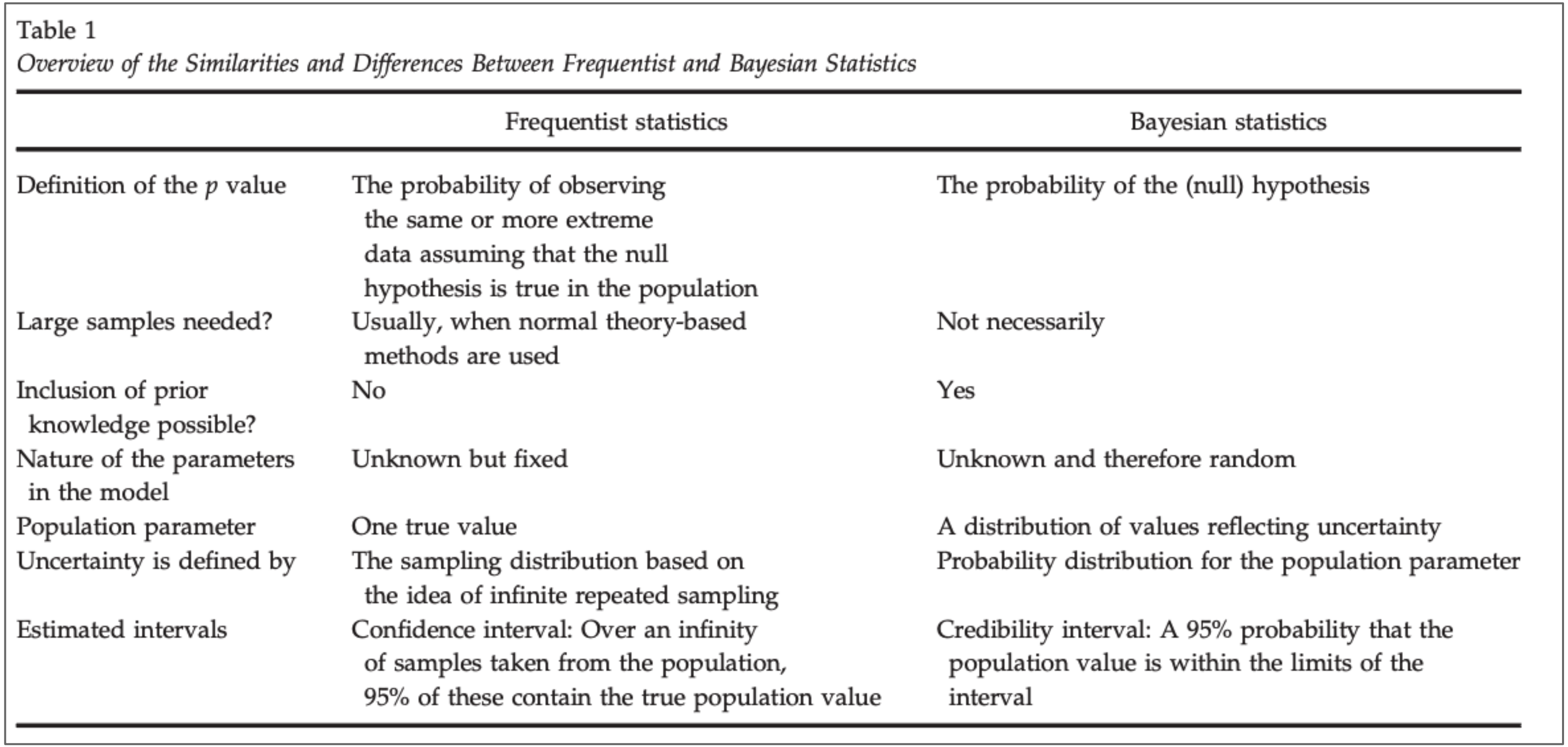


Table 1

*Overview of the Similarities and Differences Between Frequentist and Bayesian Statistics*

| | Frequentist statistics | Bayesian statistics |
|---|---|---|
| Definition of the *p* value | The probability of observing the same or more extreme data assuming that the null hypothesis is true in the population | The probability of the (null) hypothesis |
| Large samples needed? | Usually, when normal theory-based methods are used | Not necessarily |
| Inclusion of prior knowledge possible? | No | Yes |
| Nature of the parameters in the model | Unknown but fixed | Unknown and therefore random |
| Population parameter | One true value | A distribution of values reflecting uncertainty |
| Uncertainty is defined by | The sampling distribution based on the idea of infinite repeated sampling | Probability distribution for the population parameter |
| Estimated intervals | Confidence interval: Over an infinity of samples taken from the population, 95% of these contain the true population value | Credibility interval: A 95% probability that the population value is within the limits of the interval |

This table is from: Van de Schoot, R., Kaplan, D., Denissen, J., Asendorpf, J. B., Neyer, F. J., & Van Aken, M. A. (2014). A gentle introduction to Bayesian analysis: Applications to developmental research. Child development, 85(3), 842-860.
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4158865/

# Rules of Thumb for Bayes Factor Interpretations

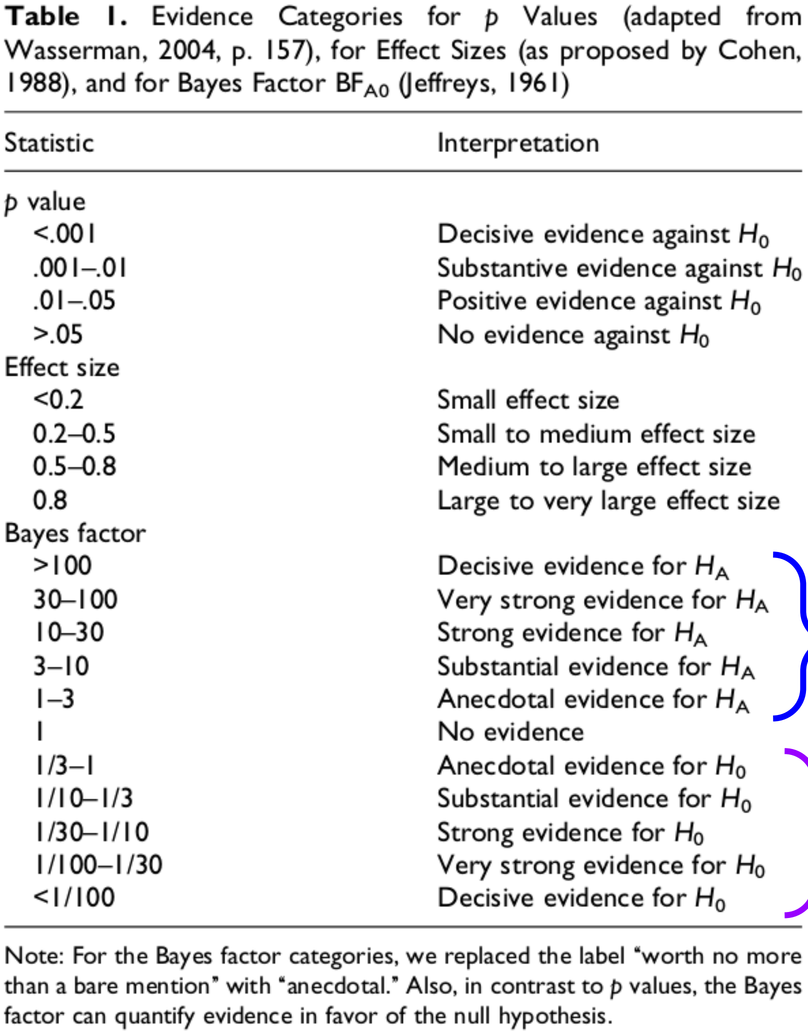


**Table 1.** Evidence Categories for *p* Values (adapted from Wasserman, 2004, p. 157), for Effect Sizes (as proposed by Cohen, 1988), and for Bayes Factor $BF_{A0}$ (Jeffreys, 1961)

| Statistic | Interpretation |
|---|---|
| *p* value | |
| <.001 | Decisive evidence against $H_0$ |
| .001–.01 | Substantive evidence against $H_0$ |
| .01–.05 | Positive evidence against $H_0$ |
| >.05 | No evidence against $H_0$ |
| Effect size | |
| <0.2 | Small effect size |
| 0.2–0.5 | Small to medium effect size |
| 0.5–0.8 | Medium to large effect size |
| 0.8 | Large to very large effect size |
| Bayes factor | |
| >100 | Decisive evidence for $H_A$ |
| 30–100 | Very strong evidence for $H_A$ |
| 10–30 | Strong evidence for $H_A$ |
| 3–10 | Substantial evidence for $H_A$ |
| 1–3 | Anecdotal evidence for $H_A$ |
| 1 | No evidence |
| 1/3–1 | Anecdotal evidence for $H_0$ |
| 1/10–1/3 | Substantial evidence for $H_0$ |
| 1/30–1/10 | Strong evidence for $H_0$ |
| 1/100–1/30 | Very strong evidence for $H_0$ |
| <1/100 | Decisive evidence for $H_0$ |

Note: For the Bayes factor categories, we replaced the label "worth no more than a bare mention" with "anecdotal." Also, in contrast to *p* values, the Bayes factor can quantify evidence in favor of the null hypothesis.

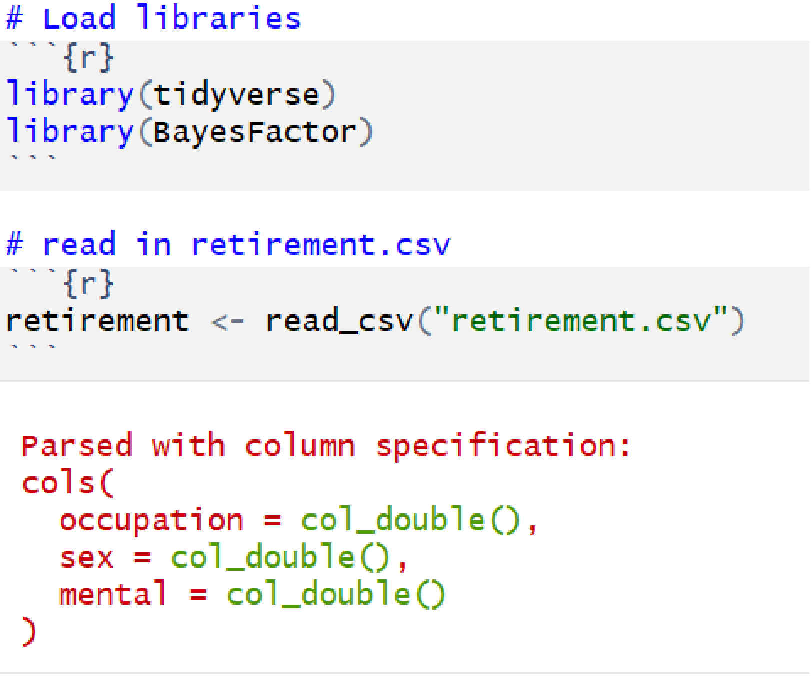
Bayes factors are indices of *relative* evidence of one model (or hypothesis) over another

Evidence for alternative hypothesis (compared to null hypothesis)

Evidence for null hypothesis (compared to alternative hypothesis)

Wetzels et al., 2011
https://journals.sagepub.com/doi/abs/10.1177/1745691611406923

# Load libraries and read in data



~~~~
# Load libraries
```{r}
library(tidyverse)
library(BayesFactor)
```

read in retirement.csv
```{r}
retirement <- read_csv("retirement.csv")
```
~~~~

```
Parsed with column specification:
cols(
  occupation = col_double(),
  sex = col_double(),
  mental = col_double()
)
```

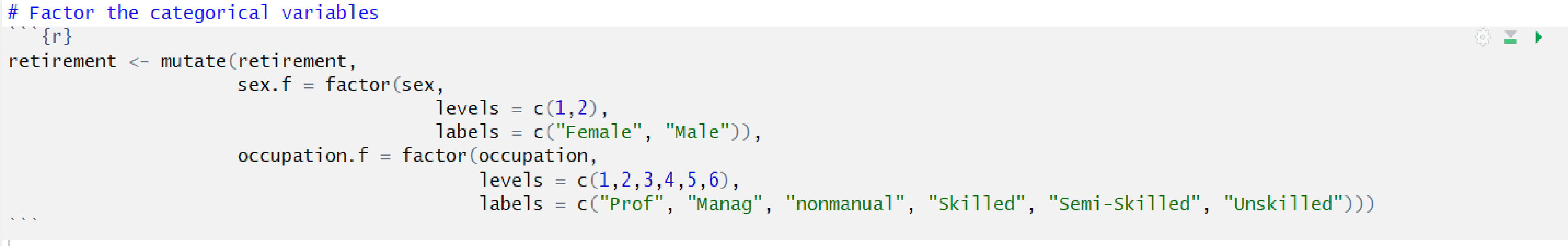
The retirement dataset has N=1910 for 3 variables:

Occupation: 1 = professor, 2 = manager, 3 = non manual worker, 4 = skilled worker, 5 = semi-skilled worker, 6 = unskilled worker

Sex: 1 = female, 2 = male

Mental: Continuous outcome variable indicating mental health (1-5)

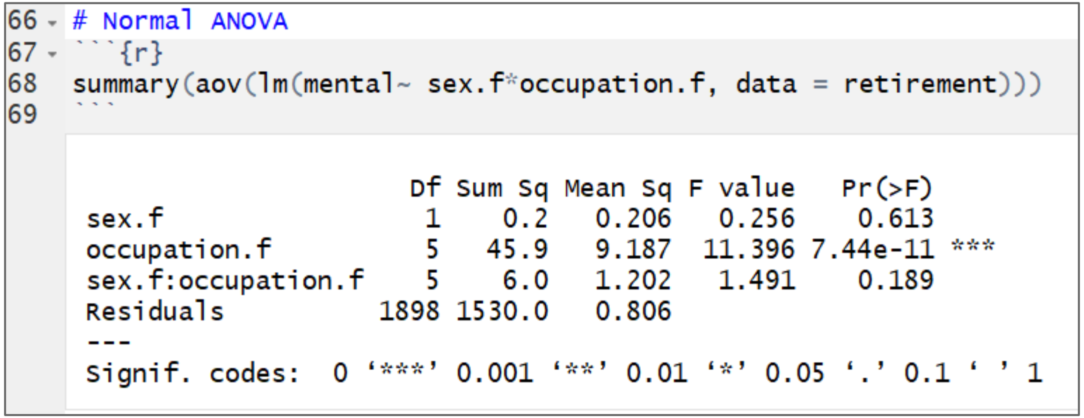
Factor the categorical variables



~~~
# Factor the categorical variables
```{r}
retirement <- mutate(retirement,
                     sex.f = factor(sex,
                                       levels = c(1,2),
                                       labels = c("Female", "Male")),
                     occupation.f = factor(occupation,
                                           levels = c(1,2,3,4,5,6),
                                           labels = c("Prof", "Manag", "nonmanual", "Skilled", "Semi-Skilled", "Unskilled")))
```
~~~

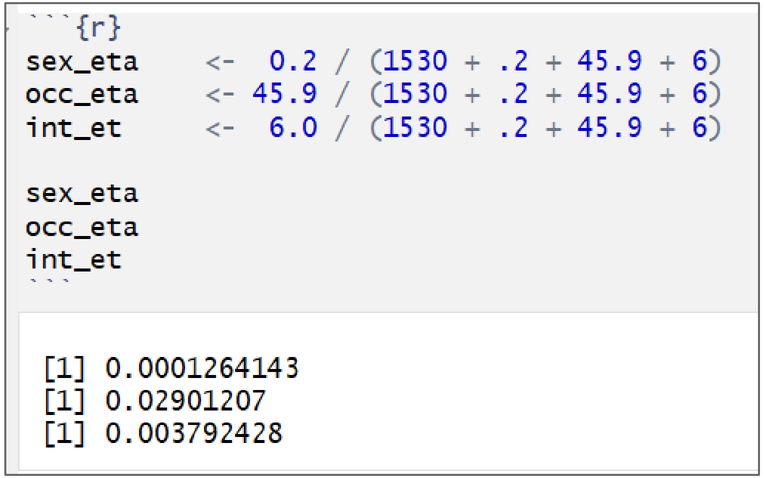
Tell R to read sex identity and occupation as categorical when conducting analyses

1) Conduct a regular ANOVA in which gender, occupation, and the interaction between the two predict mental health



~~~
# Normal ANOVA
```{r}
summary(aov(lm(mental~ sex.f*occupation.f, data = retirement)))
```
~~~

```
                     Df Sum Sq Mean Sq F value   Pr(>F)    
sex.f                 1    0.2   0.206   0.256    0.613    
occupation.f          5   45.9   9.187  11.396 7.44e-11 ***
sex.f:occupation.f    5    6.0   1.202   1.491    0.189    
Residuals          1898 1530.0   0.806                     
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

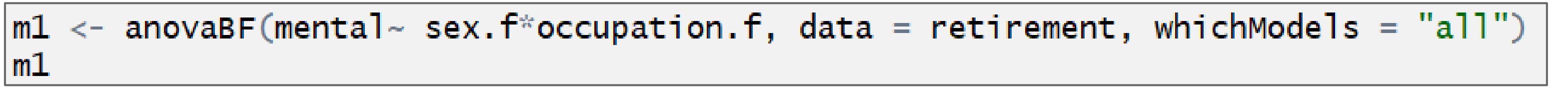


~~~
```{r}
sex_eta     <-  0.2 / (1530 + .2 + 45.9 + 6)
occ_eta     <- 45.9 / (1530 + .2 + 45.9 + 6)
int_et      <-  6.0 / (1530 + .2 + 45.9 + 6)

sex_eta
occ_eta
int_et
```
~~~

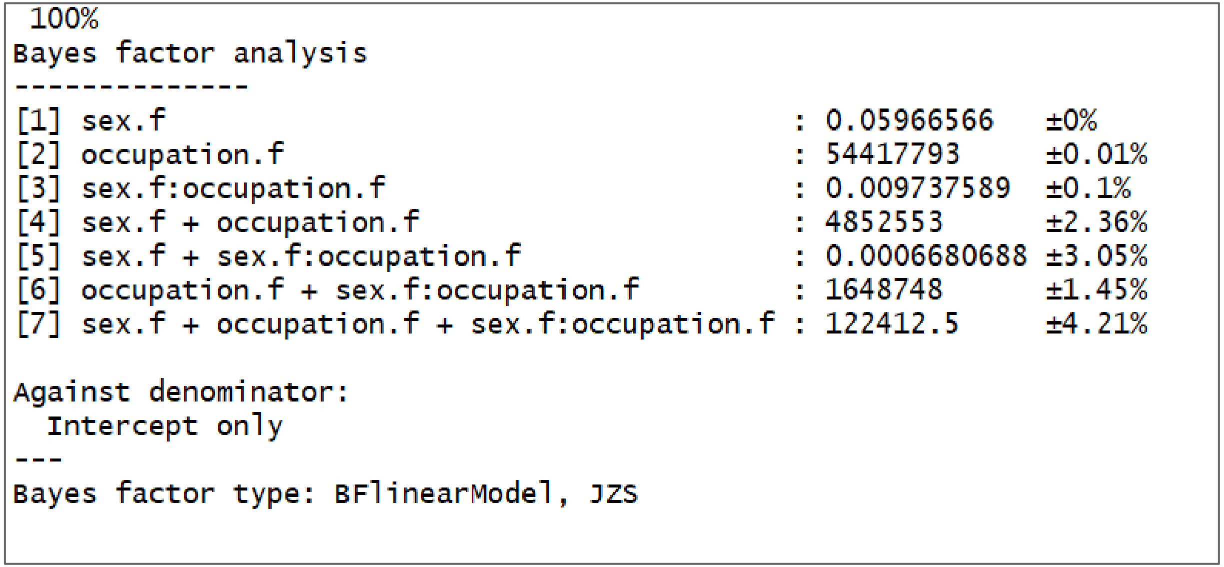
```
[1] 0.0001264143
[1] 0.02901207
[1] 0.003792428
```

Results indicate that only the main effect of occupation significantly predicts mental health.
This effect has the largest eta squared value, suggesting that occupation explains ~3% of the variance in mental health.

2) Conduct a bayesian ANOVA, starting with all models



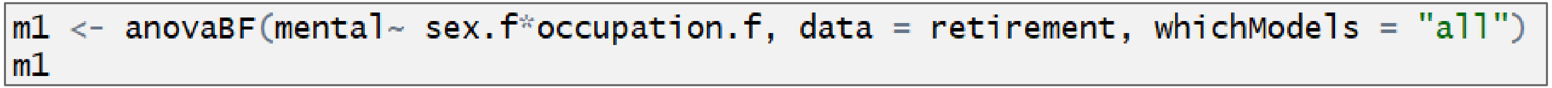
```
m1 <- anovaBF(mental~ sex.f*occupation.f, data = retirement, whichModels = "all")
m1
```



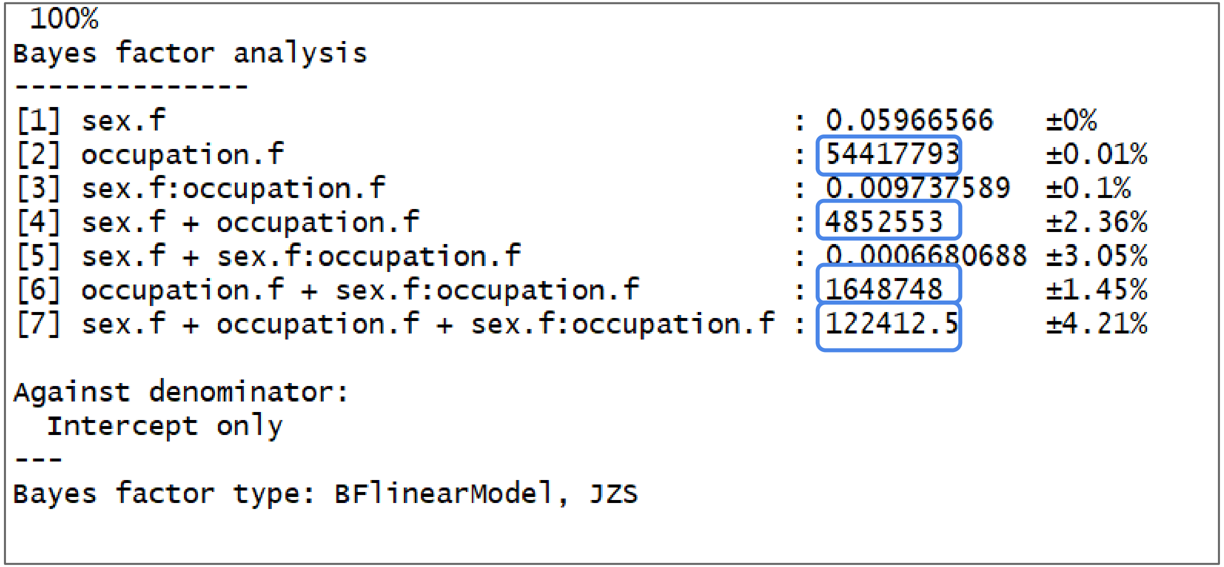
```
 100%
Bayes factor analysis
--------------
[1] sex.f                                  : 0.05966566   ±0%
[2] occupation.f                           : 54417793     ±0.01%
[3] sex.f:occupation.f                     : 0.009737589  ±0.1%
[4] sex.f + occupation.f                   : 4852553      ±2.36%
[5] sex.f + sex.f:occupation.f             : 0.0006680688 ±3.05%
[6] occupation.f + sex.f:occupation.f      : 1648748      ±1.45%
[7] sex.f + occupation.f + sex.f:occupation.f : 122412.5     ±4.21%

Against denominator:
  Intercept only
---
Bayes factor type: BFlinearModel, JZS
```

Gives us the bayes factor for each possible model (i.e., all combinations of effects that we can test).
In this notation, a:b denotes an interaction term.

2) Conduct a bayesian ANOVA, starting with all models



```
m1 <- anovaBF(mental~ sex.f*occupation.f, data = retirement, whichModels = "all")
m1
```



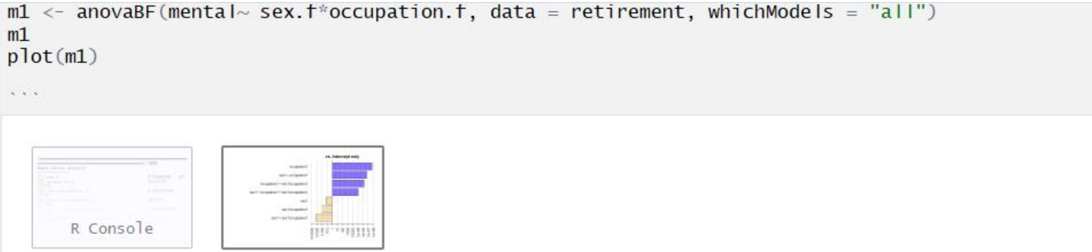
```
 100%
Bayes factor analysis
--------------
[1] sex.f                                  : 0.05966566    ±0%
[2] occupation.f                           : 54417793      ±0.01%
[3] sex.f:occupation.f                     : 0.009737589   ±0.1%
[4] sex.f + occupation.f                   : 4852553       ±2.36%
[5] sex.f + sex.f:occupation.f             : 0.0006680688 ±3.05%
[6] occupation.f + sex.f:occupation.f      : 1648748       ±1.45%
[7] sex.f + occupation.f + sex.f:occupation.f : 122412.5   ±4.21%

Against denominator:
  Intercept only
---
Bayes factor type: BFlinearModel, JZS
```

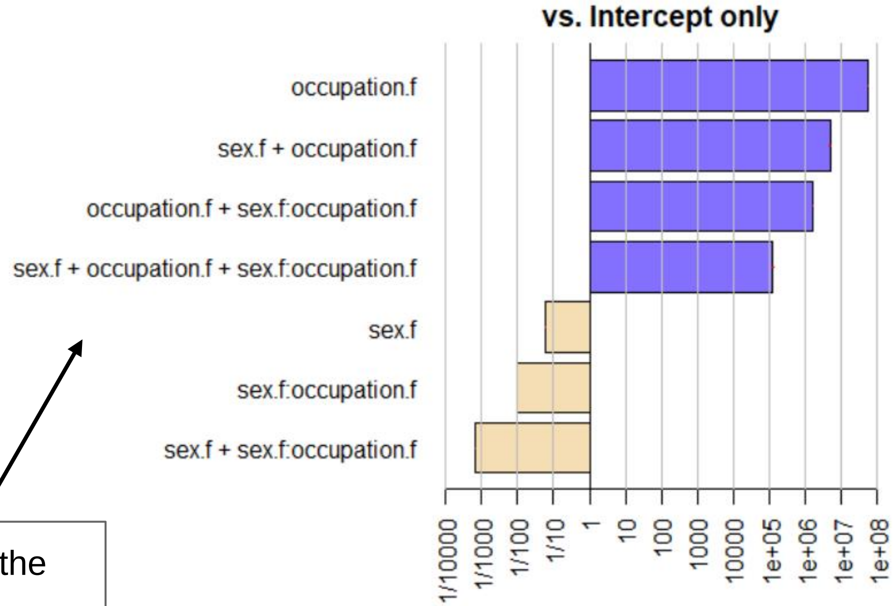
Main takeaway:

Models that include occupation as a main effect have large bayes factors

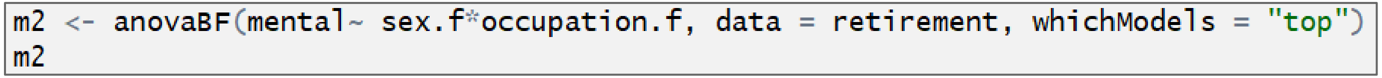
BF > 100 = “decisive evidence for H_A”

2a) Plot the bayes factor values for all models

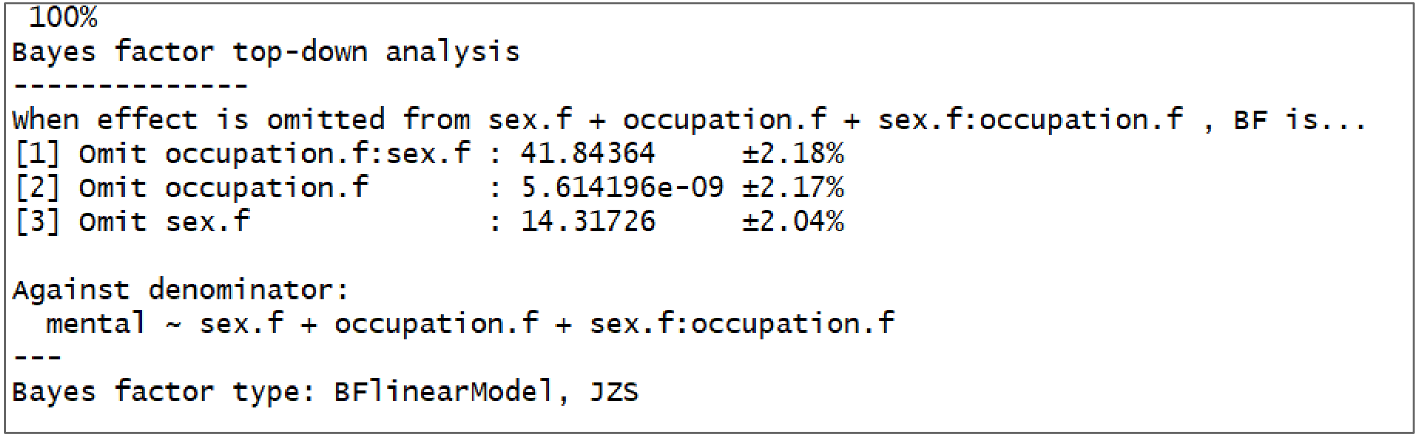


```
m1 <- anovaBF(mental~ sex.f*occupation.f, data = retirement, whichModels = "all")
m1
plot(m1)

```
```



Remember, a BF of 1 = no evidence for either the H_A or the H_O

🟪 = evidence for H_A

🟨 = evidence for H_O

y-axis = the models

x-axis = bayes factor (BF)
```

# 3) Conduct a bayesian ANOVA, using a “top-down” approach



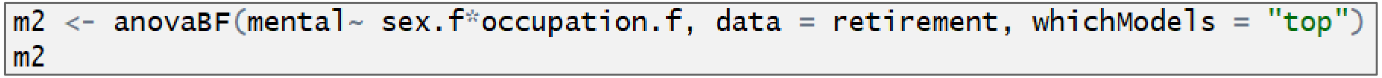
```
m2 <- anovaBF(mental~ sex.f*occupation.f, data = retirement, whichModels = "top")
m2
```



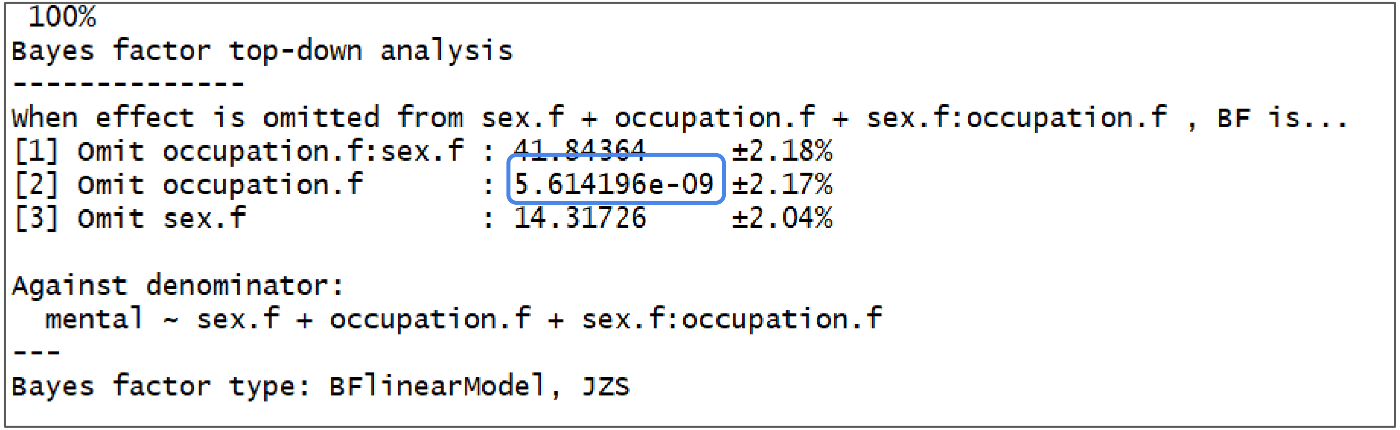
```
 100%
Bayes factor top-down analysis
--------------
When effect is omitted from sex.f + occupation.f + sex.f:occupation.f , BF is...
[1] Omit occupation.f:sex.f : 41.84364     ±2.18%
[2] Omit occupation.f       : 5.614196e-09 ±2.17%
[3] Omit sex.f              : 14.31726     ±2.04%

Against denominator:
  mental ~ sex.f + occupation.f + sex.f:occupation.f
---
Bayes factor type: BFlinearModel, JZS
```

Gives us the change in the model’s bayes factor when each effect is *eliminated* one at a time

3) Conduct a bayesian ANOVA, using a “top-down” approach



```
m2 <- anovaBF(mental~ sex.f*occupation.f, data = retirement, whichModels = "top")
m2
```



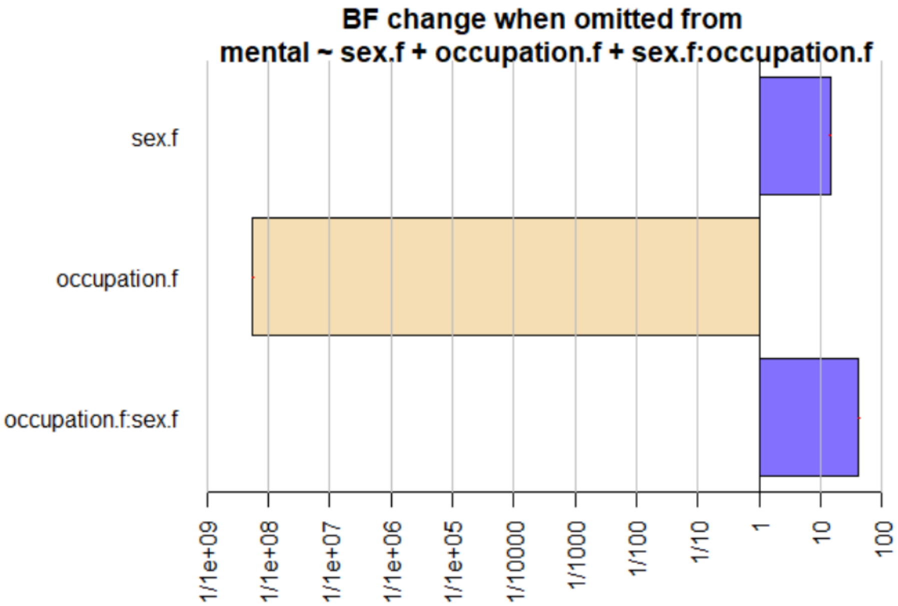
```
 100%
Bayes factor top-down analysis
--------------
When effect is omitted from sex.f + occupation.f + sex.f:occupation.f , BF is...
[1] Omit occupation.f:sex.f : 41.84364     ±2.18%
[2] Omit occupation.f       : 5.614196e-09 ±2.17%
[3] Omit sex.f              : 14.31726     ±2.04%

Against denominator:
  mental ~ sex.f + occupation.f + sex.f:occupation.f
---
Bayes factor type: BFlinearModel, JZS
```

Main takeaway:

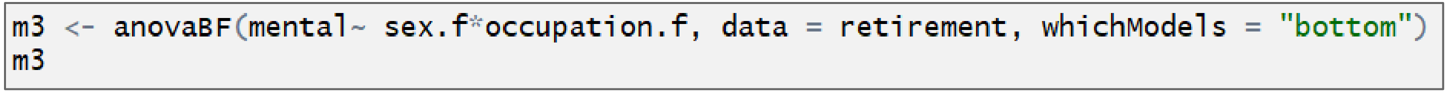
Removing occupation leaves a model with a very small bayes factor

3a) Plot the change in bayes factor values for the “top-down” approach

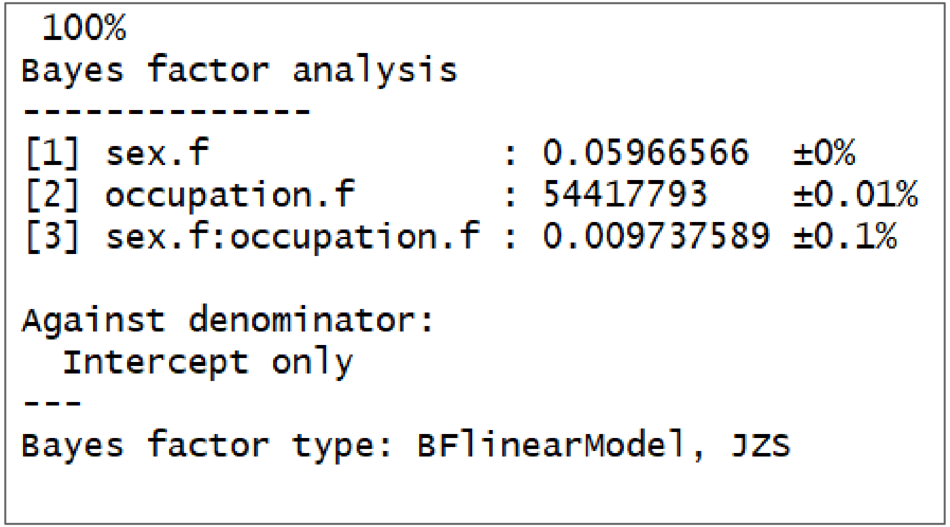
```
m2 <- anovaBF(mental~ sex.f*occupation.f, data = retirement, whichModels = "top")
m2
plot(m2)
```



4) Conduct a bayesian ANOVA, using a “bottom-up” approach



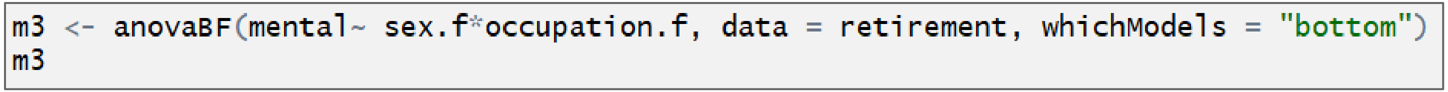
```
m3 <- anovaBF(mental~ sex.f*occupation.f, data = retirement, whichModels = "bottom")
m3
```



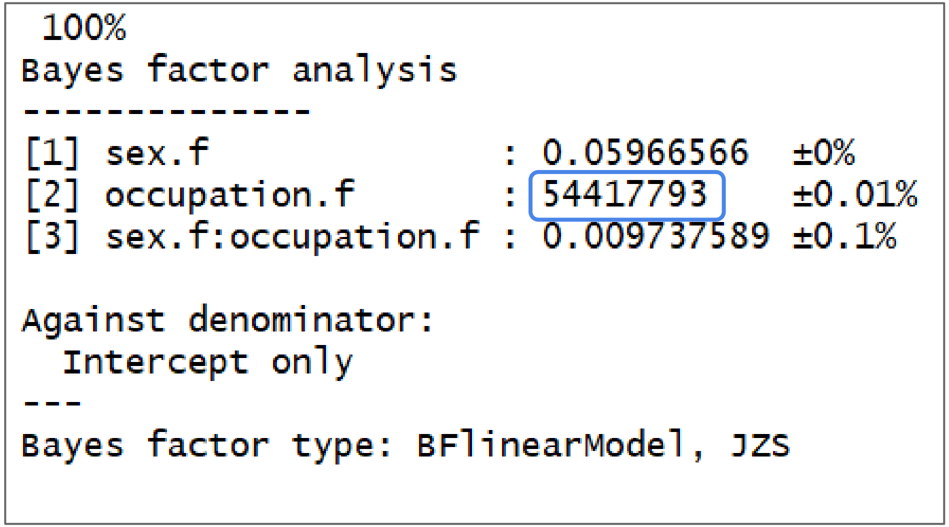
```
 100%
Bayes factor analysis
--------------
[1] sex.f                : 0.05966566  ±0%
[2] occupation.f         : 54417793    ±0.01%
[3] sex.f:occupation.f : 0.009737589 ±0.1%

Against denominator:
  Intercept only 
---
Bayes factor type: BFlinearModel, JZS
```

Gives us the change in the model’s bayes factor when each effect is *added* one at a time

4) Conduct a bayesian ANOVA, using a “bottom-up” approach



```
m3 <- anovaBF(mental~ sex.f*occupation.f, data = retirement, whichModels = "bottom")
m3
```

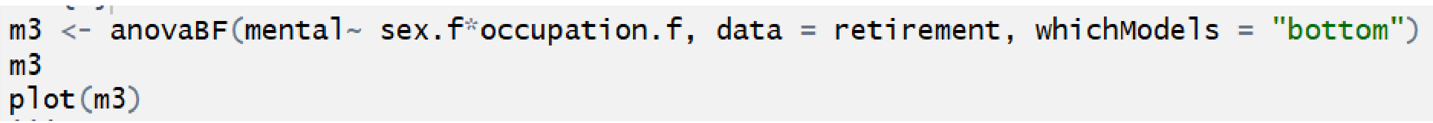


```
 100%
Bayes factor analysis
--------------
[1] sex.f                : 0.05966566  ±0%
[2] occupation.f         : 54417793    ±0.01%
[3] sex.f:occupation.f : 0.009737589 ±0.1%

Against denominator:
  Intercept only
---
Bayes factor type: BFlinearModel, JZS
```

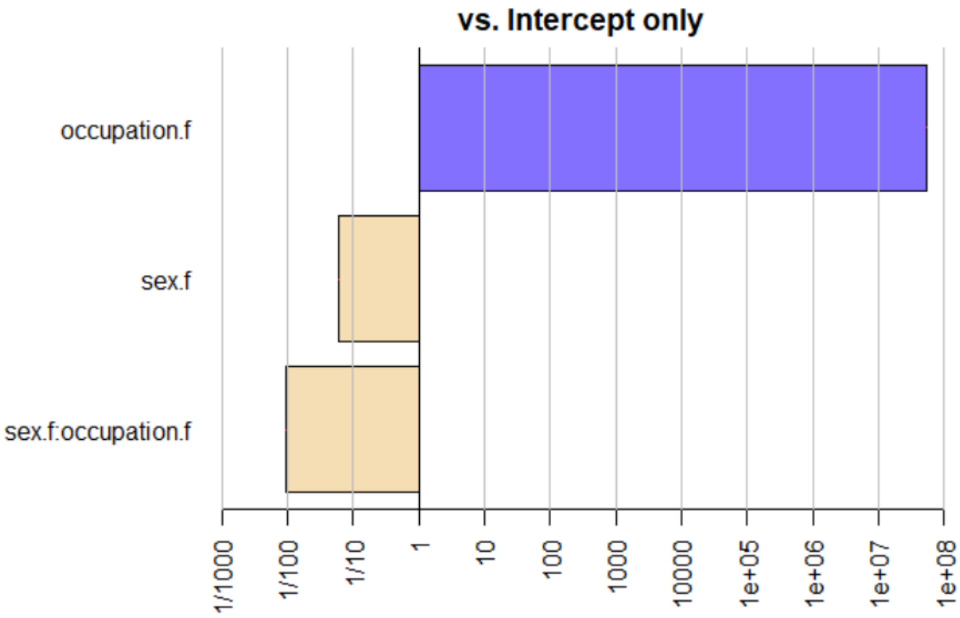
Main takeaway:

Adding occupation increases the model’s bayes factor by a large amount

4a) Plot the change in bayes factor values for the “bottom-up” approach



```
m3 <- anovaBF(mental~ sex.f*occupation.f, data = retirement, whichModels = "bottom")
m3
plot(m3)
```

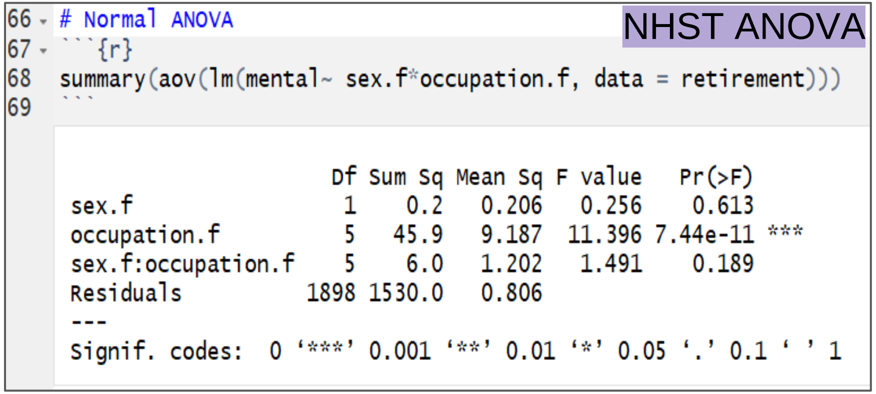


Summary of results from the Bayesian analyses

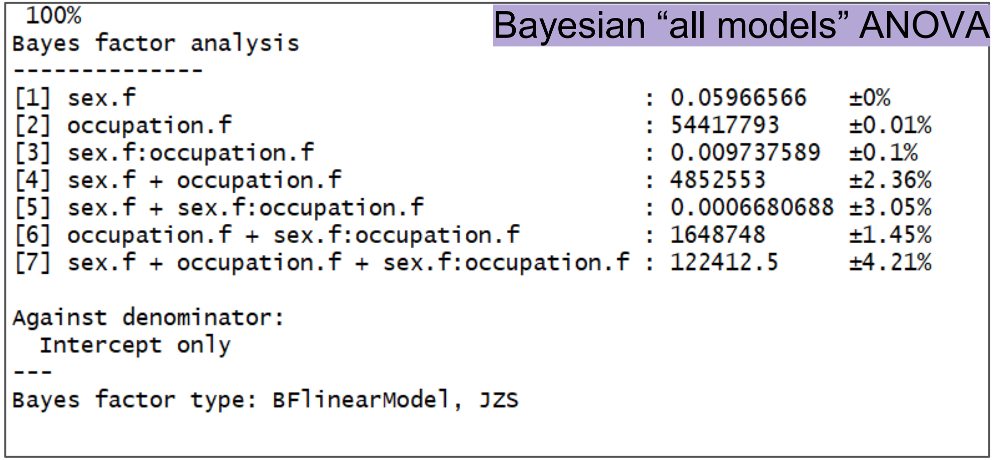
All three bayesian analysis steps (“all models”, “top-down”, and “bottom-up”) support the same conclusion:

- There is decisive evidence to support the hypothesis that occupation influences mental health.
- There is strong evidence to support the *null hypothesis* that sex identity influences mental health (i.e., the null hypothesis, stating that gender does *not* predict mental health, is likely to be true).
- There is decisive evidence to support the *null hypothesis* that the interaction between sex identity and occupation influences mental health (i.e., the null hypothesis is likely to be true).

Compare the regular ANOVA vs. Bayesian ANOVA



NHST ANOVA

~~~
# Normal ANOVA
```{r}
summary(aov(lm(mental~ sex.f*occupation.f, data = retirement)))
~~~
```

```
                      Df Sum Sq Mean Sq F value   Pr(>F)    
sex.f                  1    0.2   0.206   0.256    0.613    
occupation.f           5   45.9   9.187  11.396 7.44e-11 ***
sex.f:occupation.f     5    6.0   1.202   1.491    0.189    
Residuals           1898 1530.0   0.806                     
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```



Bayesian “all models” ANOVA

```
 100%
Bayes factor analysis
--------------
[1] sex.f                                        : 0.05966566   ±0%
[2] occupation.f                                 : 54417793     ±0.01%
[3] sex.f:occupation.f                           : 0.009737589  ±0.1%
[4] sex.f + occupation.f                         : 4852553      ±2.36%
[5] sex.f + sex.f:occupation.f                   : 0.0006680688 ±3.05%
[6] occupation.f + sex.f:occupation.f            : 1648748      ±1.45%
[7] sex.f + occupation.f + sex.f:occupation.f    : 122412.5     ±4.21%

Against denominator:
  Intercept only 
---
Bayes factor type: BFlinearModel, JZS
```

Both analyses indicate that occupation predicts mental health, while gender and gender*occupation do not.

The bayesian approach provides information that the frequentist approach does not:

- degree of evidence for the null hypothesis
- concrete statements about how well supported each model hypothesis is compared to the alternative hypothesis (e.g., null vs. alternative)
```

Additional resources on bayesian approaches

An article by Etz & Vandekerckhove (2018) about basic bayesian inferences. It opens with a quote by Dumbledore, so you know you want to read it! https://link.springer.com/article/10.3758/s13423-017-1262-3

Helpful tutorials for learning bayesian analyses using the BayesFactor package:
https://richarddmorey.github.io/BayesFactor/#fixed

More great tutorials for getting started with bayesian analyses, this time from the BayestestR package: https://cran.r-project.org/web/packages/bayestestR/vignettes/bayestestR.html

The accompanying citation for the BayestestR package can be found at: https://www.theoj.org/joss-papers/joss.01541/10.21105.joss.01541.pdf

An example of using top down and bottom-up approaches with bayesian analyses:
https://datascienceplus.com/bayesian-statistics-analysis-of-health-data/

An article by Krypotos et al. (2017) that calls for increased use of Bayesian approaches (and less NHST) in experimental psychology: https://journals.sagepub.com/doi/10.5127/jep.057316