

# Replication Bayes factors from JASP output

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Psychological Methods  
University of Amsterdam

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# Overview

- 1 Relevance and context
- 2 Bayes factors
- 3 Replication Bayes factors 1
- 4 Replication Bayes factors 2
- 5 Conclusion

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## Example: Successful Replications?

### Replication results:

- $p_{\text{orig}} = .032 < .05$ ,  $r_{\text{orig}} = 0.2$ ,  $n_{\text{orig}} = 50$
- $p_{\text{rep}} = .046 < .05$ ,  $r_{\text{rep}} = 0.1$ ,  $n_{\text{rep}} = 100$

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### Conclusion: $p$ -values and replications

- $p$ -values alone not informative, also need the direction of the effect
- To what extend? Need: **Continues measure of evidence**
- Sample sizes are relevant.
- More general, use **all** data  $d_{\text{orig}}$  and  $d_{\text{rep}}$

## Take home message

- Better method to assess hypotheses: **Bayes factors** that are continuous and take into account all the data.

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## Take home message

- Better method to assess hypotheses: **Bayes factors** that are continuous and take into account all the data.
- Better method to assess replications: **Replication Bayes factors**.
- Here instructions how to calculate them in **JASP** (<http://jasp-stats.org/>).
- Slides will be online [www.Alexander-Ly.com](http://www.Alexander-Ly.com).

# Bayes Factors

## The pros

- Evidence for  $\mathcal{M}_1$  and  $\mathcal{M}_0$



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- Comparative measure of evidence.
- Computationally hard, but we can use computers and now **JASP**
- Sensitive to prior choice

# Basics of Bayesian learning

For each model ( $\mathcal{M}_0$  and  $\mathcal{M}_1$ ) do the following:

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# Basics of Bayesian learning

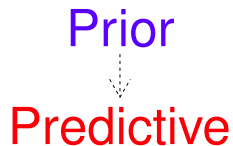
For each model ( $\mathcal{M}_0$  and  $\mathcal{M}_1$ ) do the following:

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- 5 **Repeat** Go to step 2.

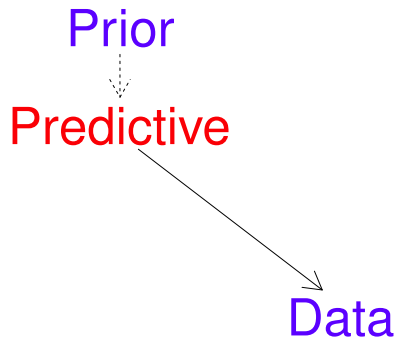
# The default prior kickstarts learning

Prior

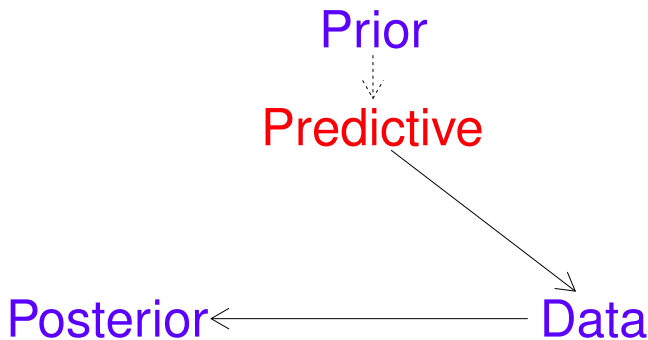
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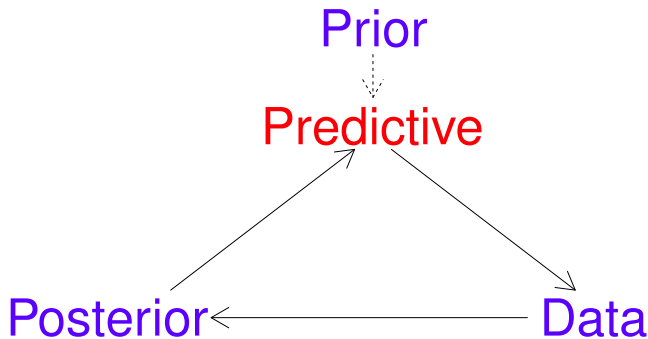
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## Example: Binomial case

### Experimental set up

- We plan to get a participant to respond to  $n = 10$  items yielding  $y$  number of correct and  $n - y$  incorrect responses.

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- We plan to get a participant to respond to  $n = 10$  items yielding  $y$  number of correct and  $n - y$  incorrect responses.
- The participant's ability  $\theta$  drives the number of correct responses  $y$ ; the closer the ability  $\theta$  is to one, the closer the number of correct responses  $y$  is to  $n$ .



## Example: Binomial case

### Experimental set up

We plan to get the participant to respond *another*  $n = 10$  items yielding  $y$  number of correct and  $n - y$  incorrect responses.

### The null model $\mathcal{M}_0$

Standard null hypothesis: The ability is known  $\mathcal{M}_0 : \theta = 1/2$

## Example: Binomial case

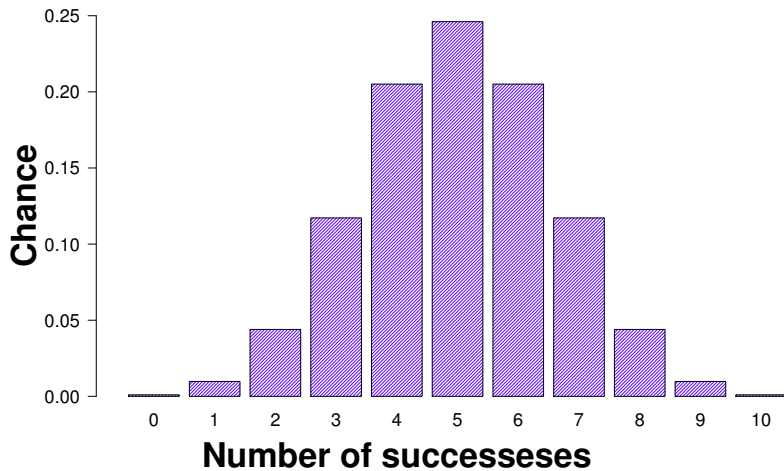
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# Binomial case: Null model $\mathcal{M}_0$ predictions



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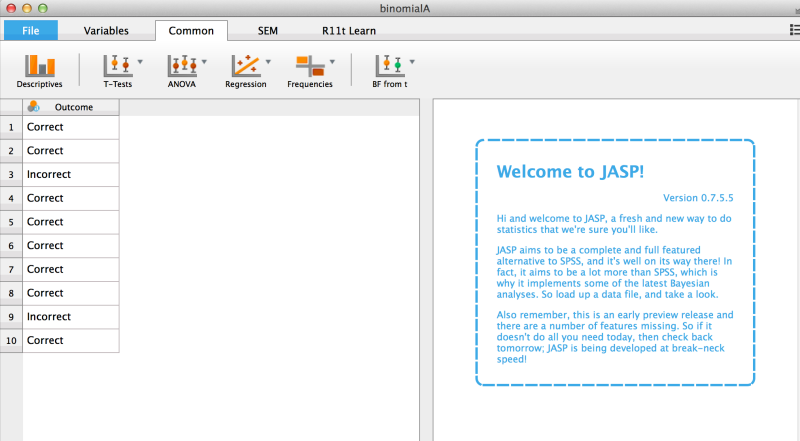
Standard null hypothesis: The ability is known  $\mathcal{M}_0 : \theta = 1/2$

**Implicit prior with zero uncertainty.**

### The alternative model $\mathcal{M}_1$

Standard alternative hypothesis: The ability is unknown:  $\mathcal{M}_1 : \theta$  is in  $(0, 1)$ . **Choose a prior in JASP.**

# The default prior in JASP: 1. Load "binomialOri.csv"



The screenshot shows the JASP software interface with the 'binomialA' dataset loaded. The 'Common' menu is active, displaying various statistical analysis options. A data table is visible on the left, and a 'Welcome to JASP!' message is displayed on the right.

	Outcome
1	Correct
2	Correct
3	Incorrect
4	Correct
5	Correct
6	Correct
7	Correct
8	Correct
9	Incorrect
10	Correct

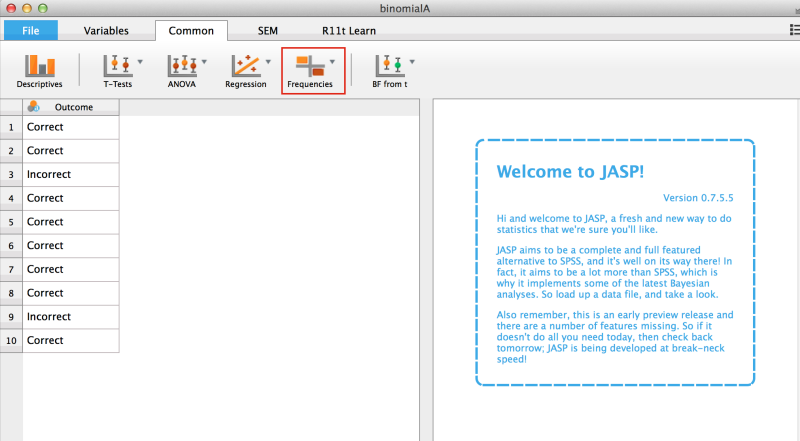
**Welcome to JASP!**  
Version 0.7.5.5

Hi and welcome to JASP, a fresh and new way to do statistics that we're sure you'll like.

JASP aims to be a complete and full featured alternative to SPSS, and it's well on its way there! In fact, it aims to be a lot more than SPSS, which is why it implements some of the latest Bayesian analyses. So load up a data file, and take a look.

Also remember, this is an early preview release and there are a number of features missing. So if it doesn't do all you need today, then check back tomorrow; JASP is being developed at break-neck speed!

# The default prior in JASP: 1. Load "binomialOri.csv"



The screenshot shows the JASP software interface. The title bar indicates the file name is "binomialA". The menu bar includes "File", "Variables", "Common", "SEM", and "R11t Learn". The "Common" menu is open, showing options for Descriptives, T-Tests, ANOVA, Regression, Frequencies (highlighted with a red box), and BF from t. The main window displays a table with 10 rows of data under the heading "Outcome".

	Outcome
1	Correct
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4	Correct
5	Correct
6	Correct
7	Correct
8	Correct
9	Incorrect
10	Correct

On the right side of the main window, there is a "Welcome to JASP!" message box with a dashed blue border. The message includes the version number "Version 0.7.5.5" and a brief introduction to the software.

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# The default prior in JASP: 2. Choose "Bayesian Binomial Test"

The screenshot shows the JASP software interface for a Bayesian Binomial Test. The window title is "binomialA\*". The "Common" tab is active, showing various statistical test options: Descriptives, T-Tests, ANOVA, Regression, Frequencies, and BF from t. The "Outcome" section is empty. The "Test value" is set to 0.5. Under "Hypothesis", the "≠ Test value" option is selected. Under "Bayes Factor", the "BF<sub>10</sub>" option is selected. Under "Plots", the "Prior and posterior" option is selected. Under "Prior", the "Beta prior: parameter a" and "Beta prior: parameter b" are both set to 1. The "Results" section displays the title "Bayesian Binomial Test" (highlighted with a red box), followed by a table with columns: Level, Counts, Total, Proportion, and BF<sub>10</sub>. The table is currently empty. A note below the table states: "Note. Proportions tested against value: 0.5."

binomialA\*

File Variables Common SEM R11t Learn

Descriptives T-Tests ANOVA Regression Frequencies BF from t

Outcome OK

Test value: 0.5

Hypothesis

- ≠ Test value
- > Test value
- < Test value

Bayes Factor

- BF<sub>10</sub>
- BF<sub>01</sub>
- Log( BF<sub>10</sub> )

Plots

- Prior and posterior
- Additional info
- Sequential analysis

Prior

Beta prior: parameter a 1

Beta prior: parameter b 1

## Results

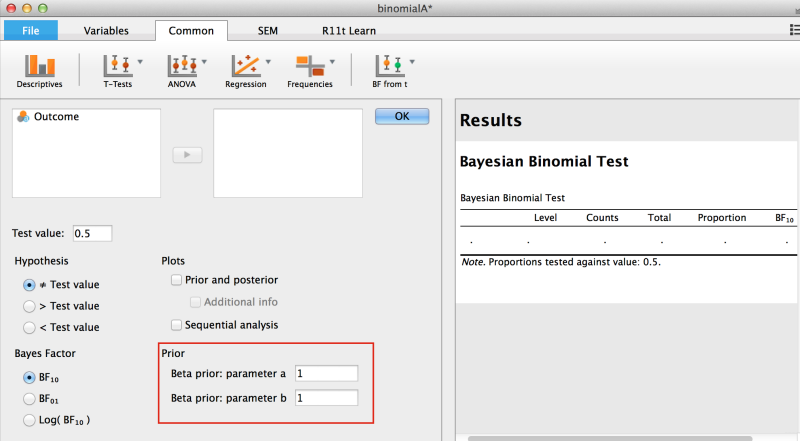
### Bayesian Binomial Test

Bayesian Binomial Test

Level	Counts	Total	Proportion	BF <sub>10</sub>
.	.	.	.	.

Note. Proportions tested against value: 0.5.

# The default prior in JASP: 3. Setting



The screenshot shows the JASP software interface for a Bayesian Binomial Test. The 'Common' tab is active, and the 'Bayes Factor from t' icon is selected. The 'Outcome' field is empty. The 'Test value' is set to 0.5. Under 'Hypothesis', the 'Test value' option is selected. Under 'Bayes Factor', the 'BF<sub>10</sub>' option is selected. The 'Prior' section is highlighted with a red box, showing 'Beta prior: parameter a' and 'Beta prior: parameter b' both set to 1. The 'Results' panel on the right displays the 'Bayesian Binomial Test' results, including a table with columns for Level, Counts, Total, Proportion, and BF<sub>10</sub>. The table is currently empty, and a note indicates that proportions were tested against a value of 0.5.

binomialA\*

File Variables Common SEM R11t Learn

Descriptives T-Tests ANOVA Regression Frequencies BF from t

Outcome [OK]

Test value: 0.5

Hypothesis

- Test value
- > Test value
- < Test value

Bayes Factor

- BF<sub>10</sub>
- BF<sub>01</sub>
- Log(BF<sub>10</sub>)

Plots

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Prior

Beta prior: parameter a 1

Beta prior: parameter b 1

## Results

### Bayesian Binomial Test

Bayesian Binomial Test

Level	Counts	Total	Proportion	BF <sub>10</sub>
.	.	.	.	.

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## The default prior in JASP: 3. Setting

### Prior

Beta prior: parameter a

Beta prior: parameter b

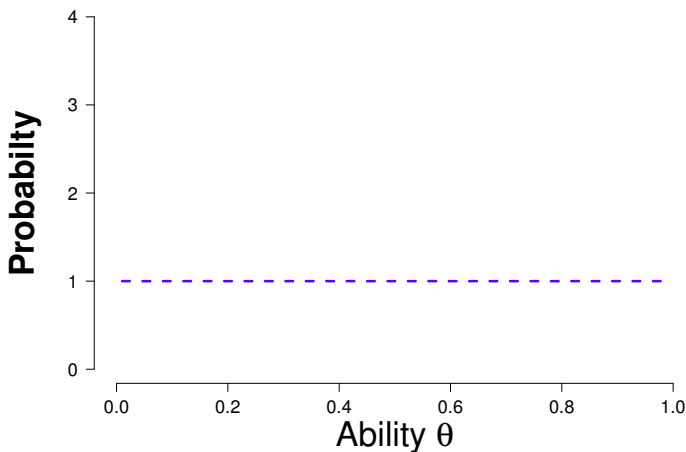
## Meaning of the default prior: Beta $a = 1, b = 1$

- Interpretation: Pre-experimentally, we saw  $a - 1$  correct and  $b - 1$  incorrect responses before the data collection.

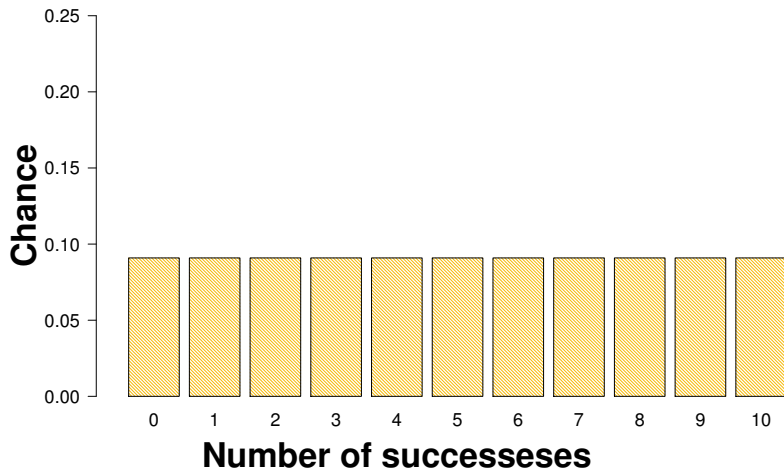
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- Interpretation: Pre-experimentally, we saw  $a - 1$  correct and  $b - 1$  incorrect responses before the data collection.
- The default specification implies 0 correct and 0 incorrect pre-responses.

# Meaning of the default prior: Beta $a = 1, b = 1$



# Binomial case: Alternative model $\mathcal{M}_1$ predictions

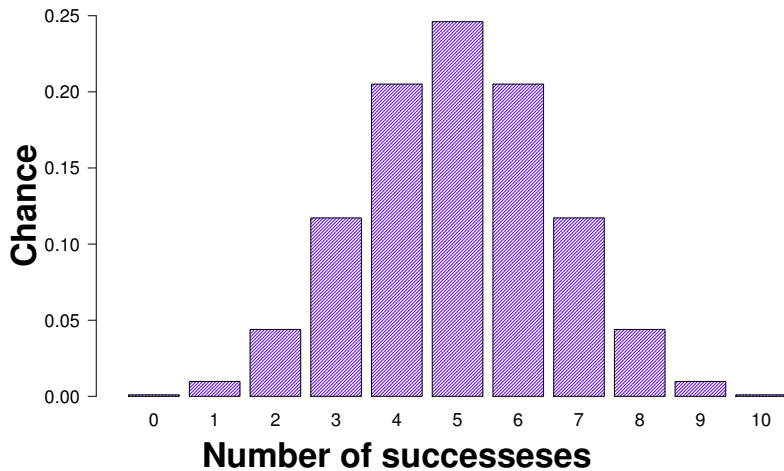


## Example: Binomial case

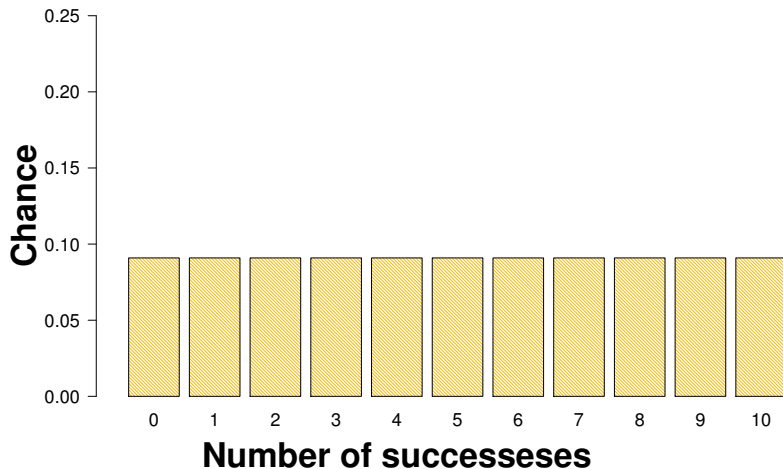
### Bayes factor

A Bayes factor compares the predictions of the two models at the observed data  $y_{\text{orig}}$

# Recall: Null model $\mathcal{M}_0$ predictions

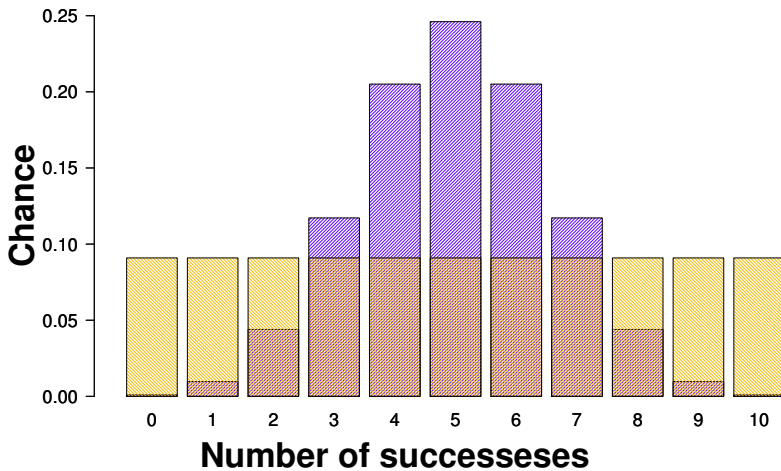


## Recall: Alternative model $\mathcal{M}_1$ predictions

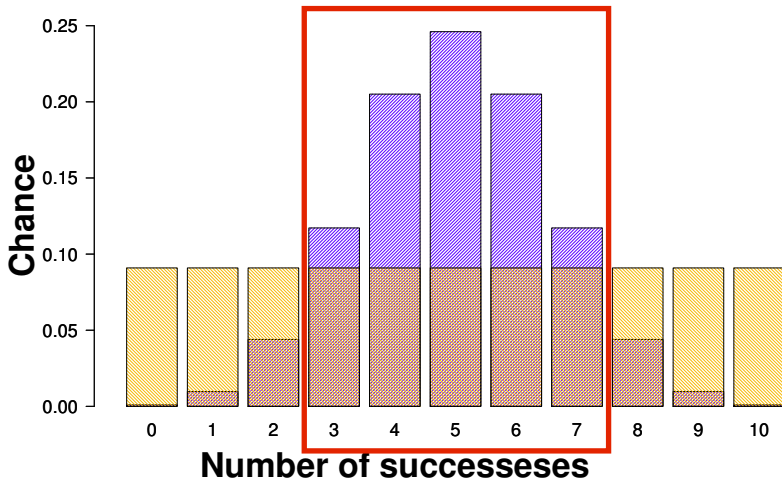




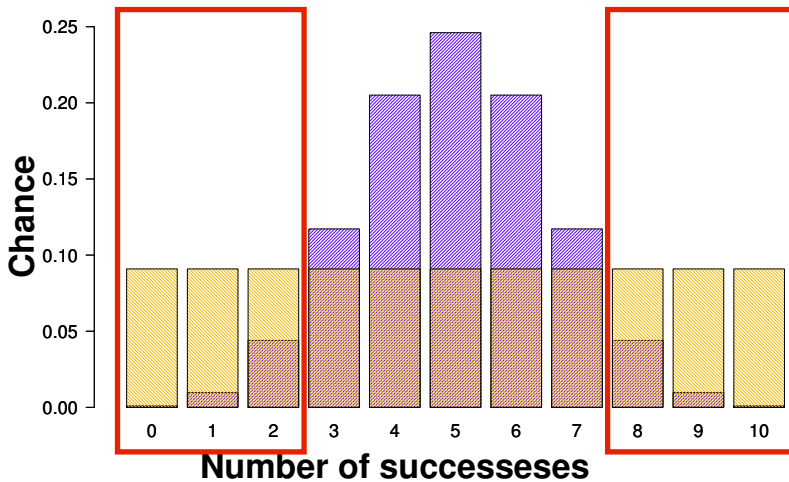
# The $\mathcal{M}_0$ vs $\mathcal{M}_1$ predictions



Null model  $\mathcal{M}_0$  "wins":  $\text{BF}_{10}(d_{\text{orig}}) < 1$



Alternative model  $\mathcal{M}_1$  "wins":  $\text{BF}_{10}(d_{\text{orig}}) > 1$



Observing data:  $y_{\text{orig}} = 8$  correct and  $n_{\text{orig}} - y_{\text{orig}} = 2$  incorrect responses

The screenshot shows the binomialA\* software interface. The main window is titled "binomialA\*" and has a menu bar with "File", "Variables", "Common", "SEM", and "R11t Learn". Below the menu bar is a toolbar with icons for Descriptives, T-Tests, ANOVA, Regression, Frequencies, and BF from t. The "Common" tab is active, showing a configuration panel for the Bayesian Binomial Test. The "Outcome" section is empty. The "Test value" is set to 0.5. The "Hypothesis" section has three radio buttons: "≠ Test value" (selected), "> Test value", and "< Test value". The "Bayes Factor" section has three radio buttons: "BF<sub>10</sub>" (selected), "BF<sub>01</sub>", and "Log(BF<sub>10</sub>)". The "Plots" section has three checkboxes: "Prior and posterior" (unchecked), "Additional info" (unchecked), and "Sequential analysis" (unchecked). The "Prior" section has two input fields: "Beta prior: parameter a" and "Beta prior: parameter b", both set to 1. The "results" panel on the right shows the title "Bayesian Binomial Test" and a table with the following structure:

Level	Counts	Total	Proportion	BF <sub>10</sub>
.	.	.	.	.

Below the table, it says "Note. Proportions tested against value: 0.5."

Observing data:  $y_{\text{orig}} = 8$  correct and  $n_{\text{orig}} - y_{\text{orig}} = 2$  incorrect responses

The screenshot shows the binomialA\* software interface. The 'Common' tab is active, and the 'Bayes from t' icon is selected. The 'Outcome' window is open, showing a play button icon. The 'Test value' is set to 0.5. The 'Hypothesis' section has '≠ Test value' selected. The 'Bayes Factor' section has 'BF<sub>10</sub>' selected. The 'Plots' section has 'Prior and posterior' selected. The 'Prior' section has 'Beta prior: parameter a' and 'Beta prior: parameter b' both set to 1. The 'results' window shows the 'Bayesian Binomial Test' results.

**Test value:** 0.5

**Hypothesis**

- ≠ Test value
- > Test value
- < Test value

**Bayes Factor**

- BF<sub>10</sub>
- BF<sub>01</sub>
- Log( BF<sub>10</sub> )

**Plots**

- Prior and posterior
- Additional info
- Sequential analysis

**Prior**

Beta prior: parameter a

Beta prior: parameter b

**results**

**Bayesian Binomial Test**

Bayesian Binomial Test

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.	.	.	.	.

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Observing data:  $y_{\text{orig}} = 8$  correct and  $n_{\text{orig}} - y_{\text{orig}} = 2$  incorrect responses

The screenshot shows the binomialA\* software interface. The 'Common' tab is active, and the 'Bayesian Binomial Test' results are displayed on the right. The test value is set to 0.5, and the hypothesis is '≠ Test value'. The Bayes Factor is set to  $BF_{10}$ . The results table shows 8 correct and 2 incorrect responses, with a total of 10. The proportion of correct responses is 0.800, and the proportion of incorrect responses is 0.200. The Bayes Factor  $BF_{10}$  is 2.069. A note indicates that proportions were tested against a value of 0.5.

Test value: 0.5

Hypothesis

- ≠ Test value
- > Test value
- < Test value

Bayes Factor

- $BF_{10}$
- $BF_{01}$
- $\text{Log}(BF_{10})$

Plots

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Prior

Beta prior: parameter a

Beta prior: parameter b

## results

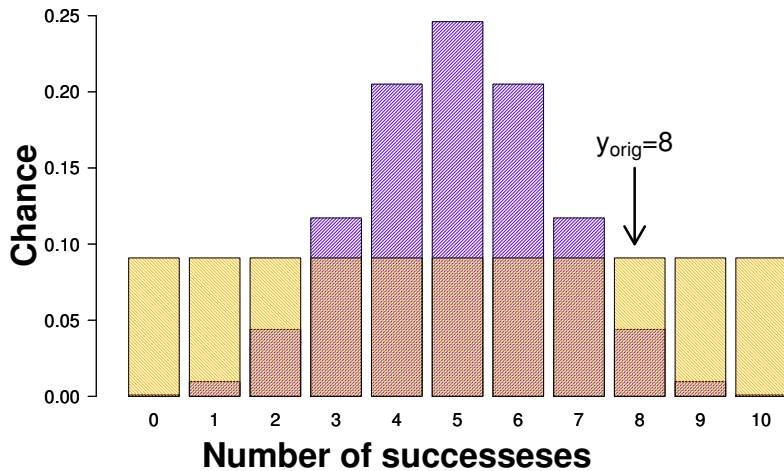
### Bayesian Binomial Test

Bayesian Binomial Test

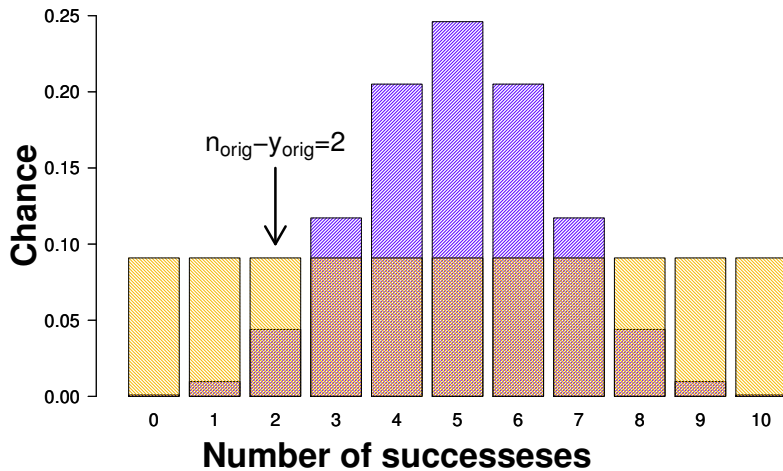
	Level	Counts	Total	Proportion	$BF_{10}$
Outcome	Correct	8	10	0.800	2.069
	Incorrect	2	10	0.200	2.069

Note. Proportions tested against value: 0.5.

# Explaining the result

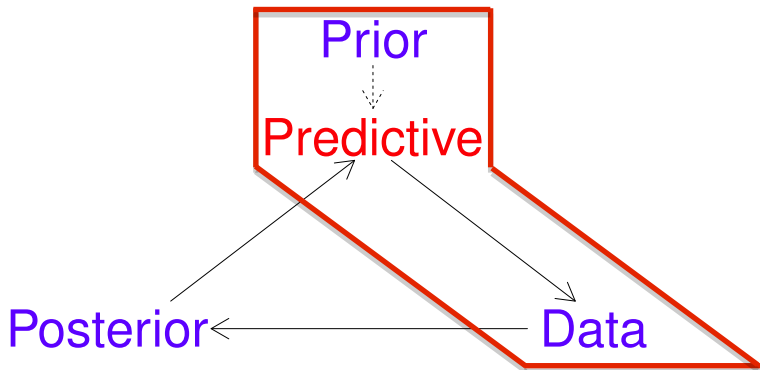


# Explaining the result

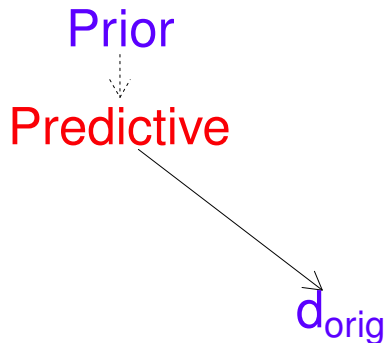




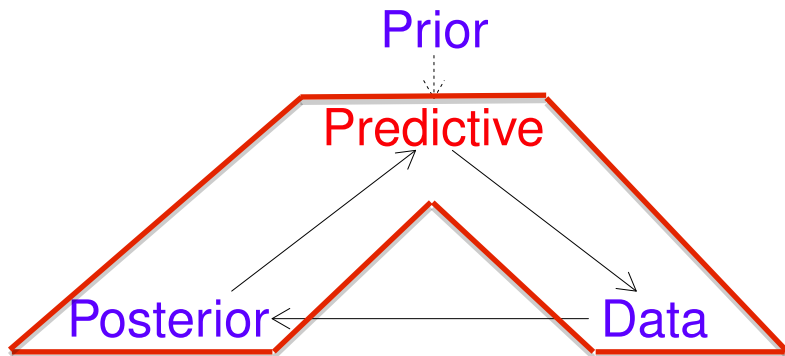
# Default Bayes factor $BF_{10}(d_{\text{orig}})$



# Default Bayes factor $BF_{10}(d_{\text{orig}})$



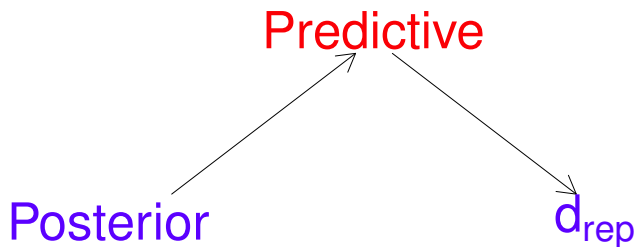
# Replication Bayes factor $BF_{10}(d_{\text{orig}} | d_{\text{rep}})$



## a. Revise the prior: Learn from the original data

Posterior  $\leftarrow$   $d_{\text{orig}}$

## b. Revise the predictions



## a. Learning from the original data

$$d_{\text{orig}} : y_{\text{orig}} = 8, n_{\text{orig}} = 10$$

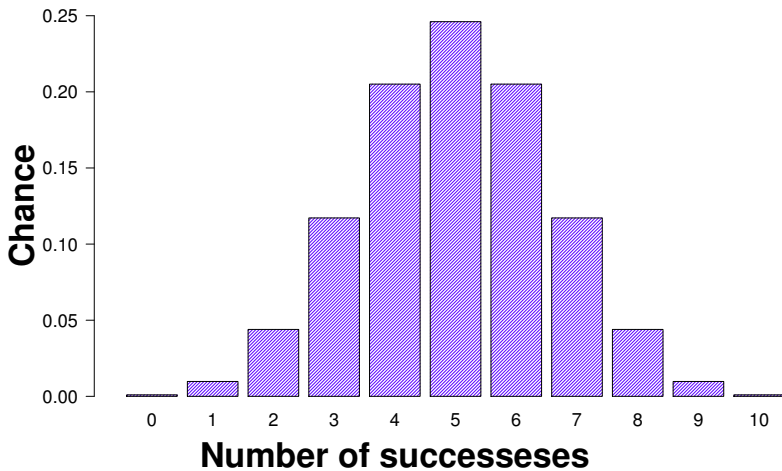
### Experimental set up

After observing  $d_{\text{orig}}$ , we plan to get the participant to respond *another*  $n = 10$  items yielding  $y$  number of correct and  $n - y$  incorrect responses.

### The null model $\mathcal{M}_0$

Revised null hypothesis: The ability is still known;  
 $\mathcal{M}_0 : \theta = 1/2$ . Same "no-uncertainty" prior.

## b. Revised: Null model $\mathcal{M}_0$ predictions



## a. Learning from the original data

$$d_{\text{orig}} : y_{\text{orig}} = 8, n_{\text{orig}} = 10$$

### Experimental set up

After observing  $d_{\text{orig}}$ , we plan to get the participant to respond *another*  $n = 10$  items yielding  $y$  number of correct and  $n - y$  incorrect responses.

### The null model $\mathcal{M}_0$

"Revised" null hypothesis: The ability is still known  $\theta = 1/2 \leftarrow$   
**Same prior.**

### The alternative model $\mathcal{M}_1$

Revised alternative hypothesis: The ability is still unknown and  $\mathcal{M}_1 : \theta$  in  $(0, 1)$ , but we are less uncertain about it.



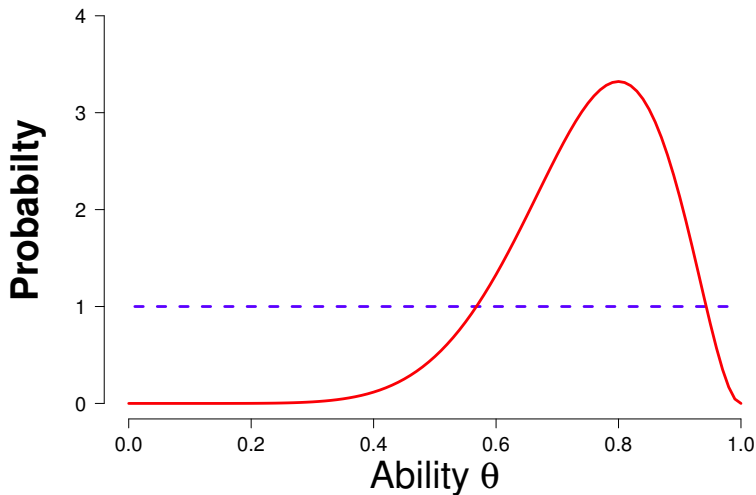
## a. Revising the prior in $\mathcal{M}_1$

- Recall: Beta prior implies that we saw  $a - 1$  correct and  $b - 1$  incorrect responses before the new data.

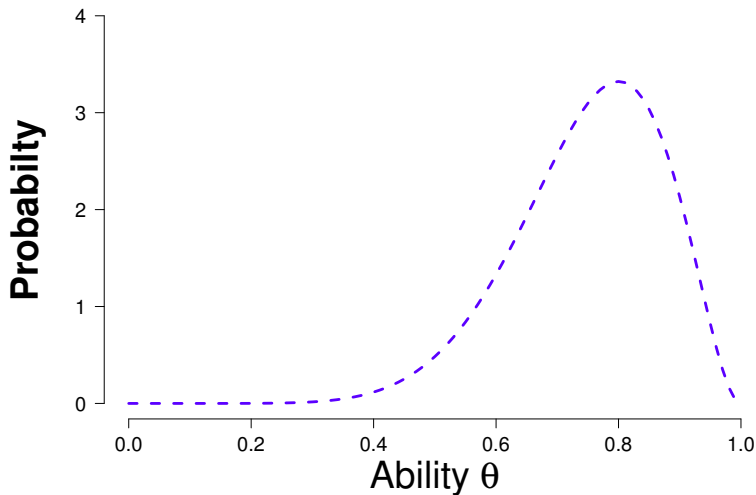
## a. Revising the prior in $\mathcal{M}_1$

- Recall: Beta prior implies that we saw  $a - 1$  correct and  $b - 1$  incorrect responses before the new data.
- With  $y_{\text{orig}} = 8$  and  $n_{\text{orig}} - y_{\text{orig}} = 2$ , this yields  $a = 9$  and  $b = 3$ , **before** seeing the replication data.

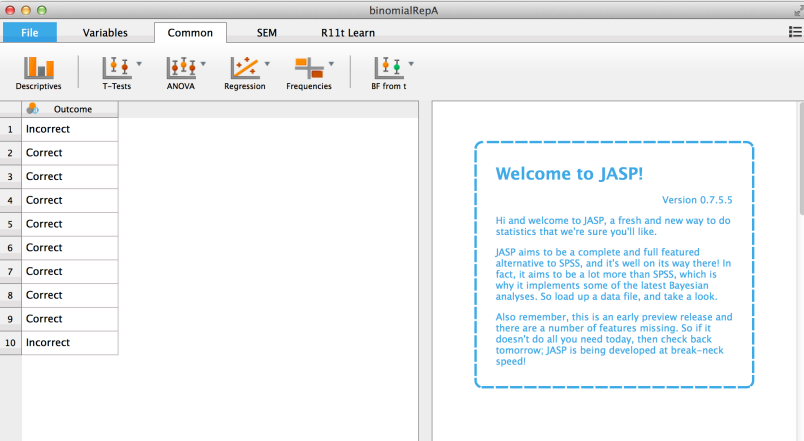
## a. Revising the prior in $\mathcal{M}_1$



## a. Revising the prior in $\mathcal{M}_1$



# Revising the prior in JASP: 1. Load "binomialRepA.csv"



The screenshot shows the JASP software interface with the file "binomialRepA" open. The "Common" tab is selected, and the "Outcome" variable is highlighted in the left-hand table. The table contains 10 rows of data. On the right side, a welcome message is displayed in a dashed blue box.

	Outcome
1	Incorrect
2	Correct
3	Correct
4	Correct
5	Correct
6	Correct
7	Correct
8	Correct
9	Correct
10	Incorrect

**Welcome to JASP!**

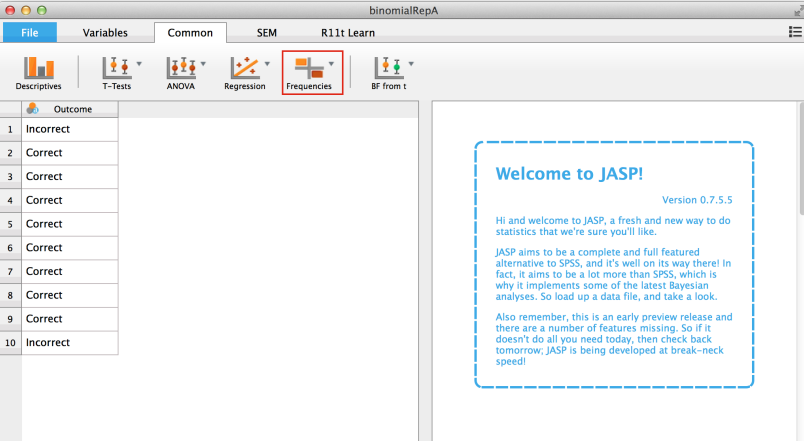
Version 0.7.5.5

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# Revising the prior in JASP: 1. Load "binomialRepA.csv"



The screenshot shows the JASP software interface with the 'binomialRepA' dataset loaded. The 'Frequencies' menu option is highlighted with a red box. The 'Outcome' variable is set to 'Incorrect'.

	Outcome
1	Incorrect
2	Correct
3	Correct
4	Correct
5	Correct
6	Correct
7	Correct
8	Correct
9	Correct
10	Incorrect

**Welcome to JASP!**

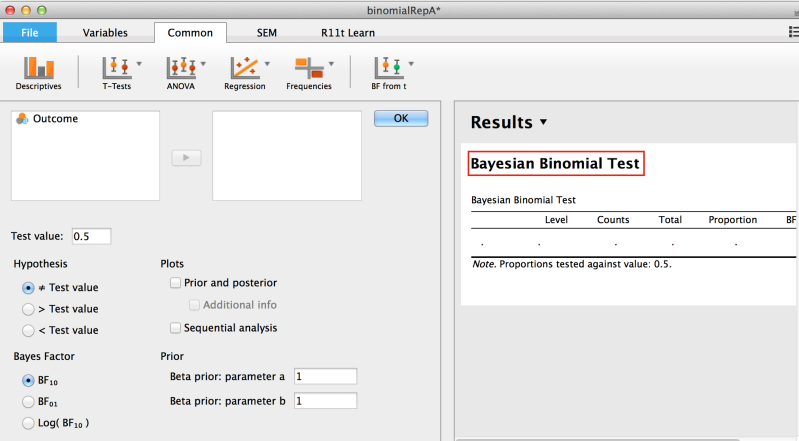
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# Revising the prior in JASP: 2. Choose "Bayesian Binomial Test"



The screenshot shows the JASP software interface for a Bayesian Binomial Test. The window title is "binomialRepA\*". The "Common" tab is selected, and the "Bayesian Binomial Test" option is highlighted in the "BF from t" section of the top toolbar.

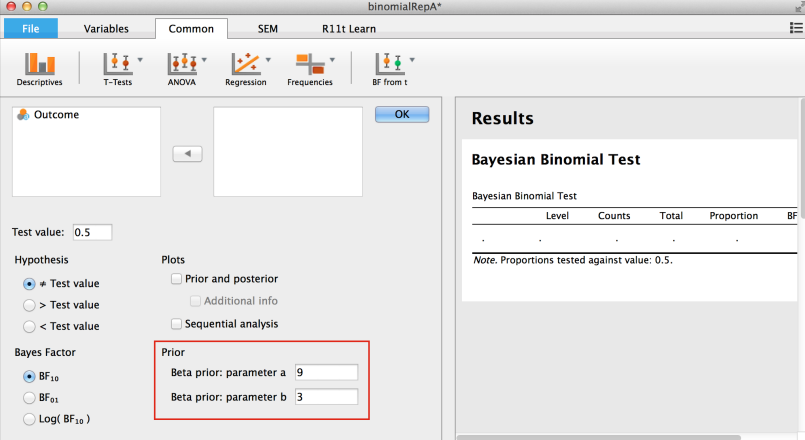
The "Outcome" section is empty. The "Test value" is set to 0.5. The "Hypothesis" section has three radio buttons:   $\neq$  Test value,   $>$  Test value, and   $<$  Test value. The "Bayes Factor" section has three radio buttons:   $BF_{10}$ ,   $BF_{01}$ , and   $\text{Log}(BF_{10})$ . The "Plots" section has three checkboxes:  Prior and posterior,  Additional info, and  Sequential analysis. The "Prior" section has two input fields: "Beta prior: parameter a" with value 1 and "Beta prior: parameter b" with value 1. An "OK" button is visible.

The "Results" section shows the following table:

Bayesian Binomial Test					
	Level	Counts	Total	Proportion	BF
.	.	.	.	.	.

Note. Proportions tested against value: 0.5.

# Revising the prior in JASP: 3. Change the prior



The screenshot displays the JASP software interface for a Bayesian Binomial Test. The window title is "binomialRepA\*". The "Common" tab is selected, showing various statistical tests. The "Outcome" variable is set to "Outcome". The "Test value" is 0.5. The "Hypothesis" is set to "≠ Test value". The "Bayes Factor" is set to "BF<sub>10</sub>". The "Prior" section is highlighted with a red box, showing "Beta prior: parameter a" set to 9 and "Beta prior: parameter b" set to 3. The "Results" panel on the right shows the test results table.

**Bayesian Binomial Test**

Bayesian Binomial Test				
Level	Counts	Total	Proportion	BF
.	.	.	.	.

*Note. Proportions tested against value: 0.5.*



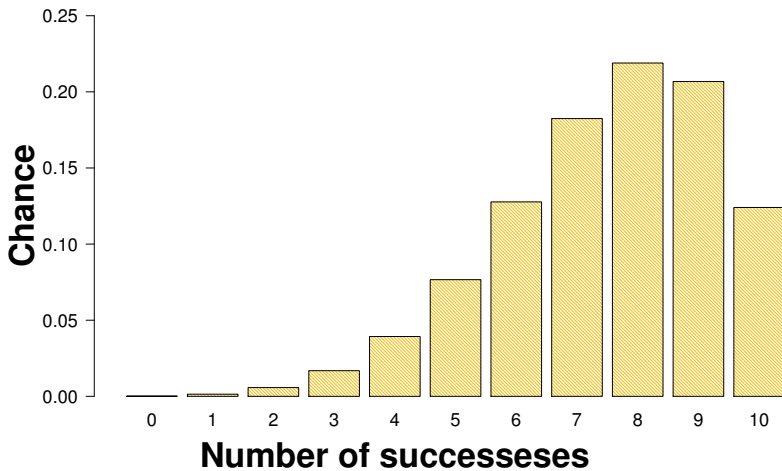
## Revising the prior in JASP: 3. Change the prior

### Prior

Beta prior: parameter a

Beta prior: parameter b

## b. Revised: Alternative model $\mathcal{M}_1$ predictions

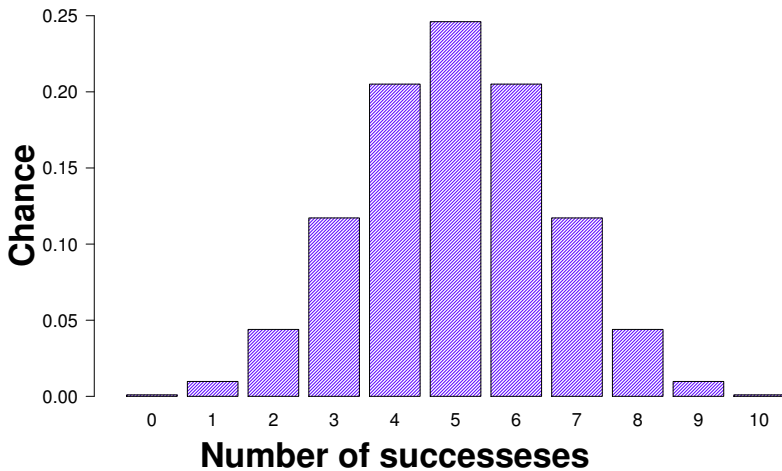


# Replication Bayes factor

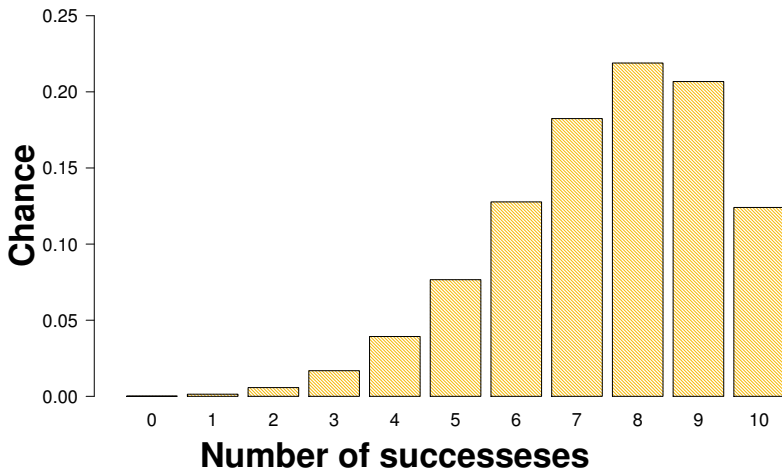
## Bayes factor

The replication Bayes factor compares the revised predictions (based on  $d_{\text{orig}}$ ) of the two models at the observed data  $y_{\text{rep}}$

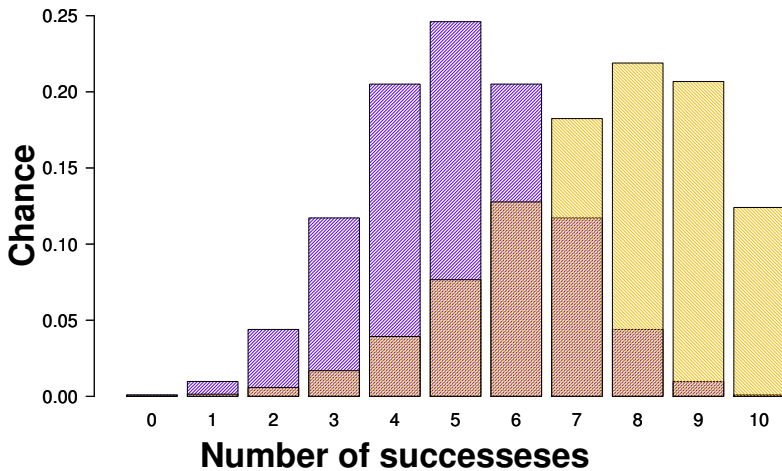
## b. Recall revised null model $\mathcal{M}_0$ predictions



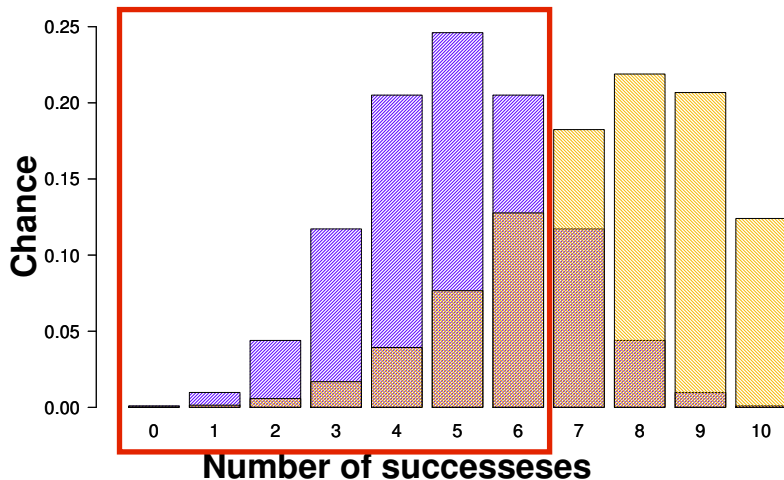
## b. Recall revised alternative model $\mathcal{M}_1$ predictions



## c. The revised $\mathcal{M}_0$ vs $\mathcal{M}_1$ predictions

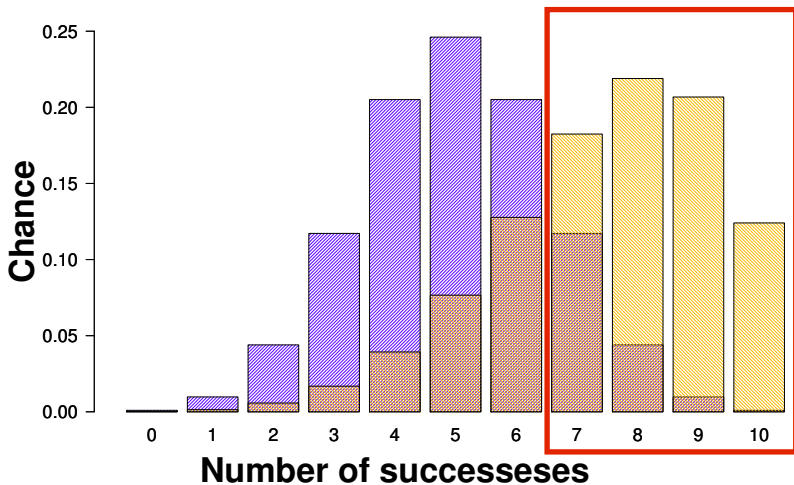


c. The revised null  $\mathcal{M}_0$  wins:  $\text{BF}_{10}(d_{\text{rep}} | d_{\text{orig}}) < 1$



c. The revised alternative  $\mathcal{M}_1$  wins:

$$\text{BF}_{10}(d_{\text{rep}} | d_{\text{orig}}) > 1$$





Example A:  $y_{\text{orig}} = 8$ ,  $n_{\text{orig}} = 10$  and  $y_{\text{rep}} = 8$ ,  $n_{\text{rep}} = 10$

The screenshot shows the binomialRepA software interface. The main window is titled "binomialRepA\*" and has a menu bar with "File", "Variables", "Common", "SEM", and "R11t Learn". Below the menu bar are icons for "Descriptives", "T-Tests", "ANOVA", "Regression", "Frequencies", and "BF from t".

The "Common" tab is active, showing a "Test value" of 0.5. Under "Hypothesis", the "Test value" option is selected. Under "Bayes Factor", the "BF<sub>10</sub>" option is selected. Under "Plots", the "Prior and posterior" option is selected. Under "Prior", the "Beta prior: parameter a" is set to 9 and "Beta prior: parameter b" is set to 3. A red box highlights a play button icon in the "Outcome" section.

The "Results" panel on the right displays the "Bayesian Binomial Test" results. It includes a table with the following structure:

Bayesian Binomial Test				
Bayesian Binomial Test				
Level	Counts	Total	Proportion	BF
.	.	.	.	.

Note: Proportions tested against value: 0.5.

Example A:  $y_{\text{orig}} = 8$ ,  $n_{\text{orig}} = 10$  and  $y_{\text{rep}} = 8$ ,  $n_{\text{rep}} = 10$

The screenshot shows the binomialRepA software interface. The main window is titled "binomialRepA\*" and has a menu bar with "File", "Variables", "Common", "SEM", and "R11t Learn". Below the menu bar are icons for "Descriptives", "T-Tests", "ANOVA", "Regression", "Frequencies", and "BF from t".

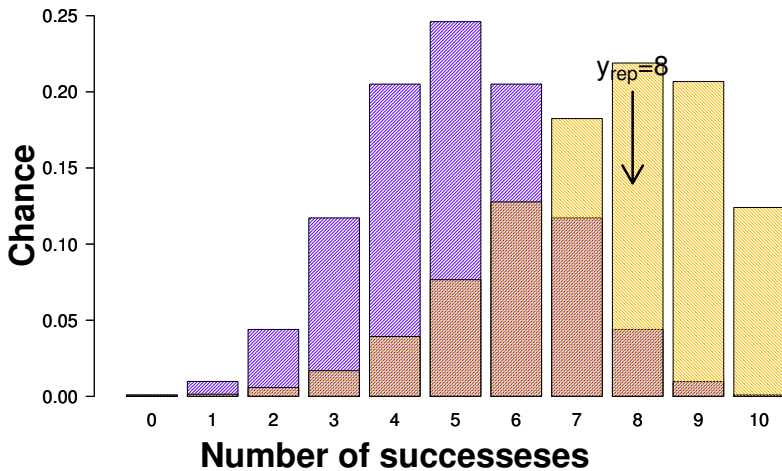
The "Common" tab is active, showing a list of variables with "Outcome" selected. A "Test value" field is set to 0.5. Under "Hypothesis", the "≠ Test value" option is selected. Under "Bayes Factor", the "BF<sub>10</sub>" option is selected. Under "Plots", the "Prior and posterior" option is selected. Under "Prior", the "Beta prior: parameter a" is set to 9 and "Beta prior: parameter b" is set to 3. An "OK" button is visible.

The "results" panel displays the "Bayesian Binomial Test" results. Below the title is a table with the following data:

		Level	Counts	Total	Proportion	BF <sub>10</sub>
Outcome	Correct		8	10	0.800	4.982
	Incorrect		2	10	0.200	0.131

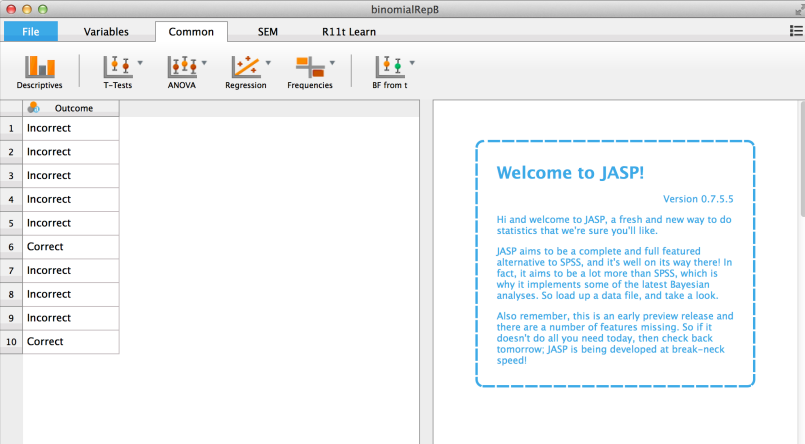
Below the table, it states: "Note. Proportions tested against value: 0.5."

Example A:  $y_{\text{orig}} = 8$ ,  $n_{\text{orig}} = 10$  and  $y_{\text{rep}} = 8$ ,  $n_{\text{rep}} = 10$



Example B:  $y_{\text{orig}} = 8$ ,  $n_{\text{orig}} = 10$  and  $y_{\text{rep}} = 2$ ,  $n_{\text{rep}} = 10$

Load "binomialRepB.csv"



The screenshot shows the JASP software interface. The window title is "binomialRepB". The menu bar includes "File", "Variables", "Common", "SEM", and "R11t Learn". The toolbar contains icons for "Descriptives", "T-Tests", "ANOVA", "Regression", "Frequencies", and "BF from t".

	Outcome
1	Incorrect
2	Incorrect
3	Incorrect
4	Incorrect
5	Incorrect
6	Correct
7	Incorrect
8	Incorrect
9	Incorrect
10	Correct

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Example B:  $y_{\text{orig}} = 8$ ,  $n_{\text{orig}} = 10$  and  $y_{\text{rep}} = 2$ ,  $n_{\text{rep}} = 10$

The screenshot shows the binomialRepB\* software interface. The main window is titled "binomialRepB\*" and has a menu bar with "File", "Variables", "Common", "SEM", and "R11t Learn". Below the menu bar are icons for "Descriptives", "T-Tests", "ANOVA", "Regression", "Frequencies", and "BF from t".

The "Common" tab is active, showing a "Test value" of 0.5. Under "Hypothesis", the "≠ Test value" option is selected. Under "Bayes Factor", the "BF<sub>10</sub>" option is selected. In the "Plots" section, the "Prior and posterior" option is selected, and the "Beta prior: parameter a" and "Beta prior: parameter b" input fields are highlighted with a red box, containing the values 9 and 3, respectively.

The "Results" panel on the right displays the "Bayesian Binomial Test" results. It includes a table with the following structure:

Bayesian Binomial Test				
Bayesian Binomial Test				
Level	Counts	Total	Proportion	BF
.	.	.	.	.

Below the table, a note states: "Note. Proportions tested against value: 0.5."

Example B:  $y_{\text{orig}} = 8$ ,  $n_{\text{orig}} = 10$  and  $y_{\text{rep}} = 2$ ,  $n_{\text{rep}} = 10$

The screenshot shows the binomialRepB\* software interface. The main window is titled "binomialRepB\*" and has a menu bar with "File", "Variables", "Common", "SEM", and "R11t Learn". Below the menu bar are icons for "Descriptives", "T-Tests", "ANOVA", "Regression", "Frequencies", and "BF from t".

The "Common" tab is active, showing the "Outcome" section with a play button icon (highlighted by a red box) and an "OK" button. Below this are input fields for "Test value: 0.5", "Hypothesis" (with radio buttons for " $\neq$  Test value", "> Test value", and "< Test value"), and "Bayes Factor" (with radio buttons for "BF<sub>10</sub>", "BF<sub>01</sub>", and "Log(BF<sub>10</sub>)").

There are also sections for "Plots" (with checkboxes for "Prior and posterior", "Additional info", and "Sequential analysis") and "Prior" (with input fields for "Beta prior: parameter a" set to 9 and "Beta prior: parameter b" set to 3).

The "Results" section on the right displays the "Bayesian Binomial Test" results. It includes a table with the following structure:

Bayesian Binomial Test				
Bayesian Binomial Test				
Level	Counts	Total	Proportion	BF
.	.	.	.	.

Below the table, a note states: "Note. Proportions tested against value: 0.5."

Example B:  $y_{\text{orig}} = 8$ ,  $n_{\text{orig}} = 10$  and  $y_{\text{rep}} = 2$ ,  $n_{\text{rep}} = 10$

The screenshot shows the binomialRepB\* software interface. The main window is titled "binomialRepB\*" and has a menu bar with "File", "Variables", "Common", "SEM", and "R11t Learn". Below the menu bar are icons for "Descriptives", "T-Tests", "ANOVA", "Regression", "Frequencies", and "BF from t".

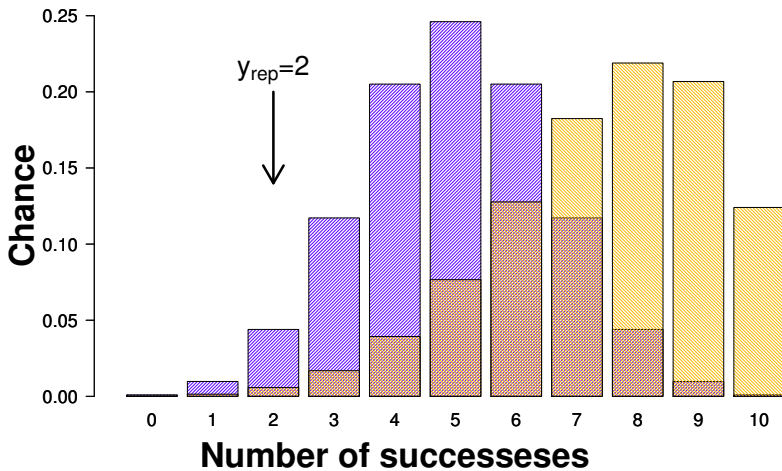
The "Common" tab is active, showing a configuration panel for a Bayesian Binomial Test. The "Outcome" variable is selected. The "Test value" is set to 0.5. The "Hypothesis" is set to " $\neq$  Test value". The "Bayes Factor" is set to "BF<sub>10</sub>". The "Beta prior" parameters are set to "parameter a" = 9 and "parameter b" = 3. The "Plots" section has "Prior and posterior" selected. The "Sequential analysis" checkbox is unchecked.

The "Results" panel on the right shows the "Bayesian Binomial Test" results. The table below is displayed:

		Level	Counts	Total	Proportion	BF <sub>10</sub>
Outcome	Correct		2	10	0.200	0.131
	Incorrect		8	10	0.800	4.982

Below the table, it states: "e. Proportions tested against value: 0.5."

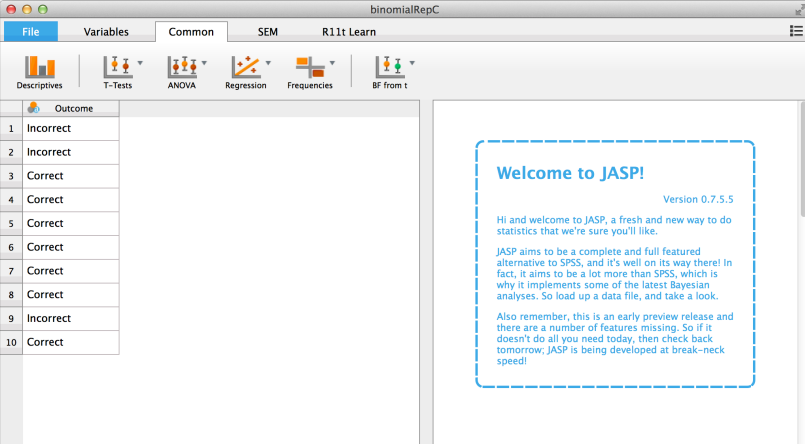
Example B:  $y_{\text{orig}} = 8$ ,  $n_{\text{orig}} = 10$  and  $y_{\text{rep}} = 2$ ,  $n_{\text{rep}} = 10$





Example C:  $y_{\text{orig}} = 8$ ,  $n_{\text{orig}} = 10$  and  $y_{\text{rep}} = 7$ ,  $n_{\text{rep}} = 10$

Load "binomialRepC.csv"



The screenshot shows the JASP software interface. The window title is "binomialRepC". The menu bar includes "File", "Variables", "Common", "SEM", and "R11t Learn". The toolbar contains icons for "Descriptives", "T-Tests", "ANOVA", "Regression", "Frequencies", and "BF from t".

	Outcome
1	Incorrect
2	Incorrect
3	Correct
4	Correct
5	Correct
6	Correct
7	Correct
8	Correct
9	Incorrect
10	Correct

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Example C:  $y_{\text{orig}} = 8$ ,  $n_{\text{orig}} = 10$  and  $y_{\text{rep}} = 7$ ,  $n_{\text{rep}} = 10$

The screenshot shows the binomialRepC software interface. The 'Common' tab is active, and the 'BF from t' option is selected. The 'Outcome' section is empty. The 'Test value' is set to 0.5. The 'Hypothesis' section has the '≠ Test value' option selected. The 'Bayes Factor' section has the 'BF<sub>10</sub>' option selected. The 'Plots' section has the 'Prior and posterior' option selected. The 'Prior' section is highlighted with a red box, showing 'Beta prior: parameter a' set to 9 and 'Beta prior: parameter b' set to 3. The 'Results' section displays the 'Bayesian Binomial Test' results, including a table with columns for Level, Counts, Total, Proportion, and BF. The table is currently empty, and a note below it states 'Note. Proportions tested against value: 0.5.'

binomialRepC\*

File Variables Common SEM R11t Learn

Descriptives T-Tests ANOVA Regression Frequencies BF from t

Outcome

Test value:

Hypothesis

≠ Test value

> Test value

< Test value

Bayes Factor

BF<sub>10</sub>

BF<sub>01</sub>

Log( BF<sub>10</sub> )

Plots

Prior and posterior

Additional info

Sequential analysis

Prior

Beta prior: parameter a

Beta prior: parameter b

Results

Bayesian Binomial Test

Level	Counts	Total	Proportion	BF
.	.	.	.	.

Note. Proportions tested against value: 0.5.

Example C:  $y_{\text{orig}} = 8$ ,  $n_{\text{orig}} = 10$  and  $y_{\text{rep}} = 7$ ,  $n_{\text{rep}} = 10$

The screenshot shows the binomialRepC software interface. The main window is titled "binomialRepC\*" and has a menu bar with "File", "Variables", "Common", "SEM", and "R11t Learn". Below the menu bar are icons for "Descriptives", "T-Tests", "ANOVA", "Regression", "Frequencies", and "BF from t".

The "Common" tab is active, showing a configuration panel for the Bayesian Binomial Test. The "Outcome" field is empty. A red box highlights a play button icon. The "Test value" is set to 0.5. The "Hypothesis" section has radio buttons for " $\neq$  Test value" (selected), "> Test value", and "< Test value". The "Bayes Factor" section has radio buttons for "BF<sub>10</sub>" (selected), "BF<sub>01</sub>", and "Log( BF<sub>10</sub> )". The "Plots" section has checkboxes for "Prior and posterior" (unchecked), "Additional info" (unchecked), and "Sequential analysis" (unchecked). The "Prior" section has input fields for "Beta prior: parameter a" (value 9) and "Beta prior: parameter b" (value 3). An "OK" button is visible.

The "Results" panel on the right displays the "Bayesian Binomial Test" results. It includes a table with the following structure:

Bayesian Binomial Test					
	Level	Counts	Total	Proportion	BF
.	.	.	.	.	.

Note. Proportions tested against value: 0.5.

Example C:  $y_{\text{orig}} = 8$ ,  $n_{\text{orig}} = 10$  and  $y_{\text{rep}} = 7$ ,  $n_{\text{rep}} = 10$

The screenshot shows the binomialRepC\* software interface. The main window is titled "binomialRepC\*" and has a menu bar with "File", "Variables", "Common", "SEM", and "R11t Learn". Below the menu bar are icons for "Descriptives", "T-Tests", "ANOVA", "Regression", "Frequencies", and "BF from t".

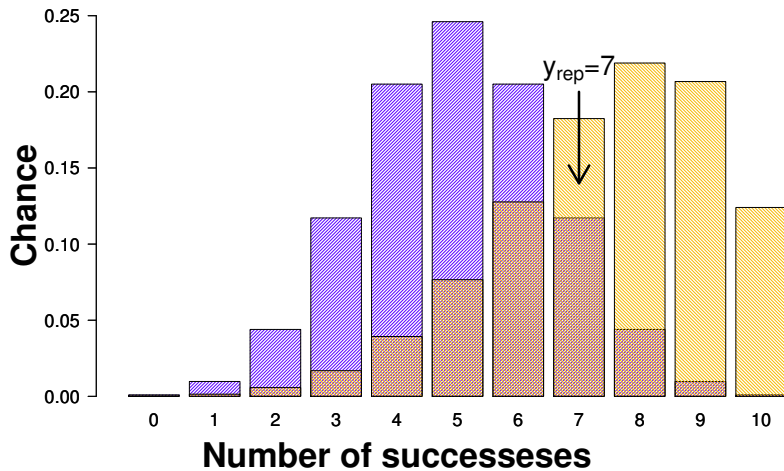
The "Common" tab is active, showing a list of variables with "Outcome" selected. A "Test value" field is set to 0.5. The "Hypothesis" section has radio buttons for "≠ Test value" (selected), "> Test value", and "< Test value". The "Bayes Factor" section has radio buttons for "BF<sub>10</sub>" (selected), "BF<sub>01</sub>", and "Log(BF<sub>10</sub>)". The "Plots" section has checkboxes for "Prior and posterior" (selected), "Additional info", and "Sequential analysis". The "Prior" section has input fields for "Beta prior: parameter a" (9) and "Beta prior: parameter b" (3). An "OK" button is visible.

The results panel on the right is titled "Results" and shows the "Bayesian Binomial Test" results. A table displays the test statistics:

Bayesian Binomial Test					
Bayesian Binomial Test					
	Level	Counts	Total	Proportion	BF <sub>10</sub>
Outcome	Correct	7	10	0.700	1.557
	Incorrect	3	10	0.300	0.144

Below the table, it states: "Proportions tested against value: 0.5."

Example C:  $y_{\text{orig}} = 8$ ,  $n_{\text{orig}} = 10$  and  $y_{\text{rep}} = 7$ ,  $n_{\text{rep}} = 10$



## Alternative method of calculation

- Replication Bayes factor as a two step method. First find the posterior based on  $d_{\text{orig}}$ , use this as prior for  $d_{\text{rep}}$ . Input in "Prior" part of JASP

## Alternative method of calculation

- Replication Bayes factor as a two step method. First find the posterior based on  $d_{\text{orig}}$ , use this as prior for  $d_{\text{rep}}$ . Input in "Prior" part of JASP
- Prior is not always easily updated.

## Alternative method of calculation

- Alternative: Calculate the replication Bayes factor as

$$\text{BF}_{10}(d_{\text{rep}} | d_{\text{orig}}) = \frac{\text{BF}_{10}(d_{\text{orig}}, d_{\text{rep}})}{\text{BF}_{10}(d_{\text{orig}})} \quad (1)$$



## Alternative method of calculation

- Alternative: Calculate the replication Bayes factor as

$$\text{BF}_{10}(d_{\text{rep}} | d_{\text{orig}}) = \frac{\text{BF}_{10}(d_{\text{orig}}, d_{\text{rep}})}{\text{BF}_{10}(d_{\text{orig}})} \quad (1)$$

- Interpretation

$$\text{BF}_{10}(d_{\text{orig}}, d_{\text{rep}}) = \text{BF}_{10}(d_{\text{rep}} | d_{\text{orig}})\text{BF}_{10}(d_{\text{orig}}) \quad (2)$$

The replication Bayes factor is the additional evidence for  $\mathcal{M}_1$  in the new data  $d_{\text{rep}}$  given that we already know  $d_{\text{orig}}$ .

## Alternative method of calculation

- Alternative: Calculate the replication Bayes factor as

$$BF_{10}(d_{\text{rep}} | d_{\text{orig}}) = \frac{BF_{10}(d_{\text{orig}}, d_{\text{rep}})}{BF_{10}(d_{\text{orig}})} \quad (1)$$

- Interpretation

$$BF_{10}(d_{\text{orig}}, d_{\text{rep}}) = BF_{10}(d_{\text{rep}} | d_{\text{orig}})BF_{10}(d_{\text{orig}}) \quad (2)$$

The replication Bayes factor is the additional evidence for  $\mathcal{M}_1$  in the new data  $d_{\text{rep}}$  given that we already know  $d_{\text{orig}}$ .

- $BF_{10}(d_{\text{rep}} | d_{\text{orig}}) < 1$ , the contribution of  $d_{\text{rep}}$  to the total evidence shrinks.

## Alternative method of calculation

- Alternative: Calculate the replication Bayes factor as

$$\text{BF}_{10}(d_{\text{rep}} | d_{\text{orig}}) = \frac{\text{BF}_{10}(d_{\text{orig}}, d_{\text{rep}})}{\text{BF}_{10}(d_{\text{orig}})} \quad (1)$$

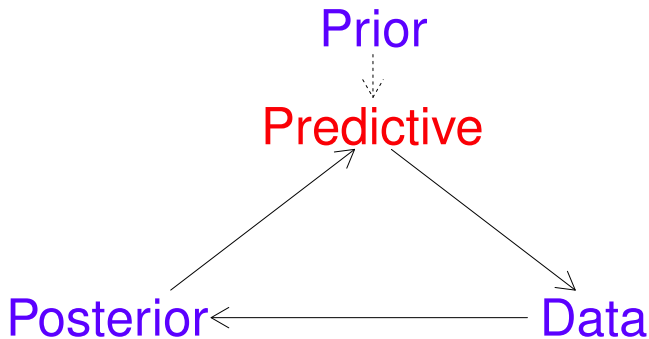
- Interpretation

$$\text{BF}_{10}(d_{\text{orig}}, d_{\text{rep}}) = \text{BF}_{10}(d_{\text{rep}} | d_{\text{orig}})\text{BF}_{10}(d_{\text{orig}}) \quad (2)$$

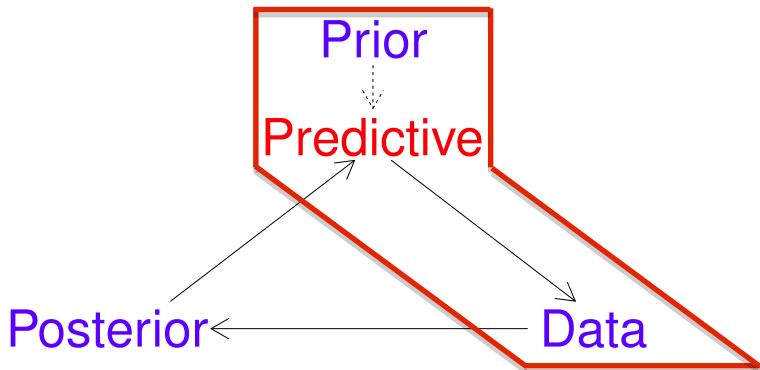
The replication Bayes factor is the additional evidence for  $\mathcal{M}_1$  in the new data  $d_{\text{rep}}$  given that we already know  $d_{\text{orig}}$ .

- $\text{BF}_{10}(d_{\text{rep}} | d_{\text{orig}}) < 1$ , the contribution of  $d_{\text{rep}}$  to the total evidence shrinks.
- $\text{BF}_{10}(d_{\text{rep}} | d_{\text{orig}}) > 1$ , the contribution of  $d_{\text{rep}}$  to the total evidence grows.

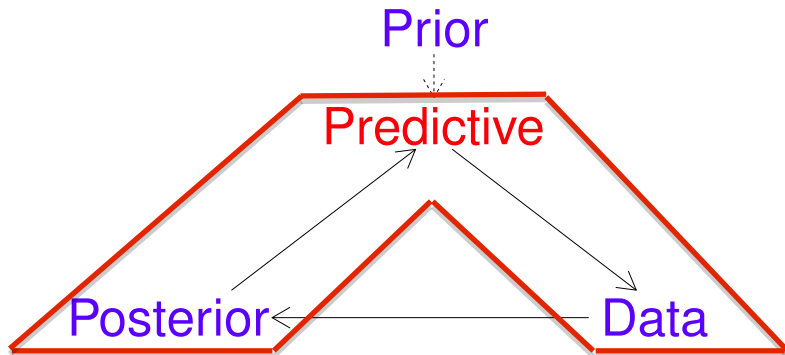
# Total Bayes factor $BF_{10}(d_{\text{orig}}, d_{\text{rep}})$



# Default Bayes factor $BF_{10}(d_{\text{orig}})$



# Replication Bayes factor $BF_{10}(d_{\text{orig}} | d_{\text{rep}})$



## Example: Orig contingency table Dai et al. (2008)

Endowed	Perceived		Total
	Fewer flowers	Fewer birds	
Flowers endowed	15	12	27
Birds endowed	8	21	29
<b>Total</b>	<b>23</b>	<b>33</b>	<b>56</b>

**Table:** Dai, Wertenbroch & Brendl (2008). "The Value Heuristic in Judgments of Relative Frequency"

### Result

Bayes factor  $BF_{10}(d_{\text{orig}}) = 2.880$

## Example: Rep contingency table Fuchs et al. (2015)

Endowed	Perceived		Total
	Fewer flowers	Fewer birds	
Flowers endowed	11	16	27
Birds endowed	14	10	24
<b>Total</b>	<b>25</b>	<b>26</b>	<b>51</b>

**Table:** Fuchs, Estel & Göllner (2015). Replication of Dai et al. (2008) (<https://osf.io/q7f6w/>)

### Result

Bayes factor  $BF_{10}(d_{rep}) = 0.720$



## Example: Combined contingency table

Endowed	Perceived		Total
	Fewer flowers	Fewer birds	
Flowers endowed	26	28	54
Birds endowed	22	31	53
<b>Total</b>	<b>48</b>	<b>59</b>	<b>107</b>

**Table:** Fuchs et al. (2015) and Dai et al. (2008) (<https://osf.io/q7f6w/>)

### Result

Bayes factor  $BF_{10}(d_{\text{orig}}, d_{\text{rep}}) = 0.298$

# Results

## Result

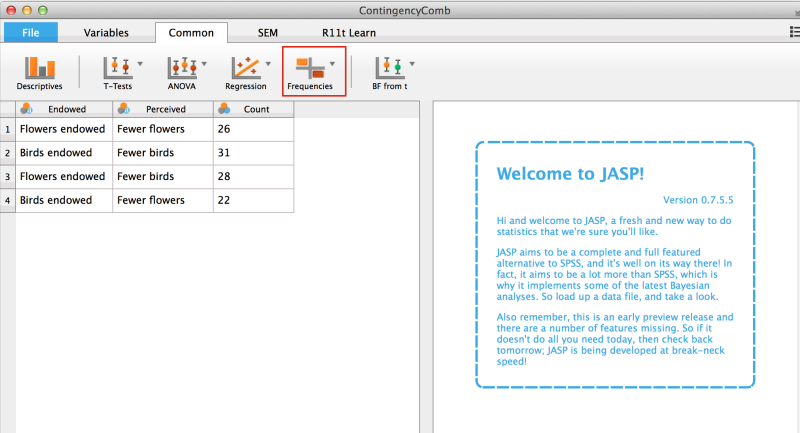
$$BF_{10}(d_{\text{rep}} | d_{\text{orig}}) \approx 0.10 \quad (3)$$

thus,

$$BF_{01}(d_{\text{rep}} | d_{\text{orig}}) \approx 9.6 \quad (4)$$

in favour of the null.

# 1. Load "contingencyComb.csv"



The screenshot shows the JASP software interface. The title bar reads "ContingencyComb". The menu bar includes "File", "Variables", "Common", "SEM", and "R11t Learn". The toolbar contains icons for "Descriptives", "T-Tests", "ANOVA", "Regression", "Frequencies" (highlighted with a red box), and "BF from t".

	Endowed	Perceived	Count
1	Flowers endowed	Fewer flowers	26
2	Birds endowed	Fewer birds	31
3	Flowers endowed	Fewer birds	28
4	Birds endowed	Fewer flowers	22

**Welcome to JASP!**

Version 0.7.5.5

Hi and welcome to JASP, a fresh and new way to do statistics that we're sure you'll like.

JASP aims to be a complete and full featured alternative to SPSS, and it's well on its way there! In fact, it aims to be a lot more than SPSS, which is why it implements some of the latest Bayesian analyses. So load up a data file, and take a look.

Also remember, this is an early preview release and there are a number of features missing. So if it doesn't do all you need today, then check back tomorrow; JASP is being developed at break-neck speed!

## 2. Choose "Bayesian Contingency Tables"

The screenshot shows the 'ContingencyComb\*' software interface. The 'Common' tab is active, and the 'Bayesian Contingency Tables' option is highlighted in the 'Results' panel. The interface includes a menu bar (File, Variables, Common, SEM, R11t Learn), a toolbar with icons for Descriptives, T-Tests, ANOVA, Regression, Frequencies, and BF from t, and a main workspace with sections for Rows, Columns, Counts, and Layers. The 'Results' panel displays the following tables:

**Bayesian Contingency Tables**

Bayesian Contingency Tables		
		Total
Total		

**Bayesian Contingency Tables Tests**

Bayesian Contingency Tables Tests		Value
BF <sub>10</sub> joint multinomial		.
N		.

### 3. Choose right analysis

The screenshot shows the 'ContingencyComb\*' software interface. The 'File' menu is open, and the 'Statistics' option is highlighted with a red box. The interface includes a toolbar with icons for Descriptives, T-Tests, ANOVA, Regression, Frequencies, and BF from t. The main window is divided into sections for Rows, Columns, Counts, and Layers. The 'Results' panel on the right displays Bayesian Contingency Tables and Bayesian Contingency Tables Tests.

**Results**

**Bayesian Contingency Tables**

Bayesian Contingency Tables		
		Total
Total		

**Bayesian Contingency Tables Tests**

Bayesian Contingency Tables Tests	
	Value
BF <sub>10</sub> joint multinomial	.
N	.

### 3. Choose right analysis

The screenshot shows the 'ContingencyComb\*' software interface. The 'Statistics' dialog box is open, and the 'Indep. multinomial, rows fixed' option is selected and highlighted with a red box. The 'Results' panel on the right displays a Bayesian Contingency Table.

**Statistics Dialog Box:**

- Sampling:**
  - Poisson
  - Joint multinomial
  - Indep. multinomial, rows fixed**
  - Indep. multinomial, columns fixed
  - Hypergeometric (2x2 only)
- Hypothesis:**
  - Group one  $\neq$  Group two
  - Group one  $>$  Group two
  - Group one  $<$  Group two
- Bayes Factor:**
  - $BF_{10}$
  - $BF_{01}$
  - $\text{Log}(BF_{10})$
- Additional Statistics:**
  - Log odds ratio (2x2 only)  
Credible interval: 95 %
  - Cramer's V**  
Credible interval: 95 %
- Plots:**
  - Log odds ratio (2x2 only)
  - Additional info
  - Cramer's V**
- Prior:**
  - Prior concentration: 1

**Results Panel:**

#### Bayesian Contingency Tables

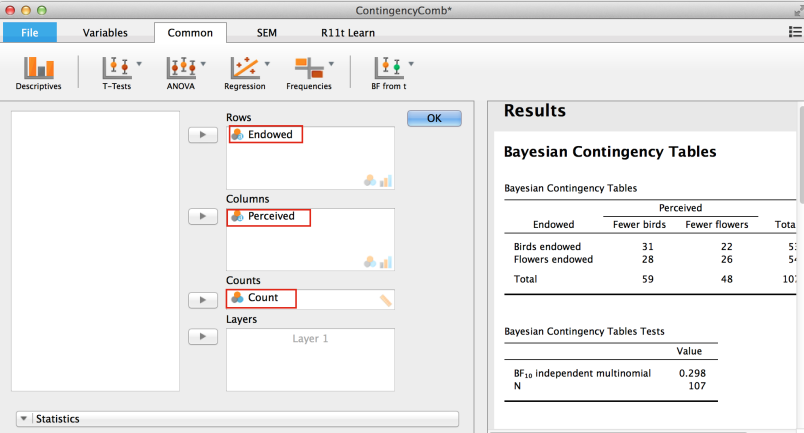
Bayesian Contingency Tables

		Total
.	.	.
.	.	.
.	.	.
Total	.	.

Bayesian Contingency Tables Tests

	Value
$BF_{10}$ independent multinomial	.
N	.

## 4. Fill in table



The screenshot shows the 'ContingencyComb\*' software interface. The 'Common' tab is active, and the following variables are selected:

- Rows: Endowed
- Columns: Perceived
- Counts: Count
- Layers: Layer 1

The 'Results' panel displays the following Bayesian Contingency Table:

	Perceived		Total
	Endowed	Fewer birds Fewer flowers	
Birds endowed	31	22	53
Flowers endowed	28	26	54
Total	59	48	107

Below the table, the Bayesian Contingency Tables Tests are shown:

	Value
BF <sub>10</sub> independent multinomial	0.298
N	107

## 5. Write down result

The screenshot shows the 'ContingencyComb\*' software interface. The 'Results' panel displays the following data:

### Bayesian Contingency Tables

Bayesian Contingency Tables

	Perceived		Total
	Endowed	Fewer birds Fewer flowers	
Birds endowed	31	22	53
Flowers endowed	28	26	54
Total	59	48	107

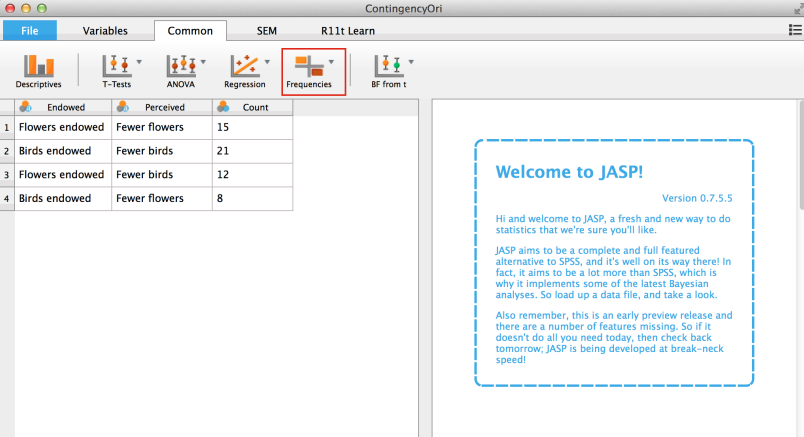
  

### Bayesian Contingency Tables Tests

	Value
BF <sub>10</sub> independent multinomial	0.298
N	107



# 1. Load "contingencyOri.csv"



The screenshot shows the JASP software interface with the 'ContingencyOri' window open. The 'Common' tab is selected, and the 'Frequencies' icon is highlighted with a red box. The main area displays a contingency table with the following data:

	Endowed	Perceived	Count
1	Flowers endowed	Fewer flowers	15
2	Birds endowed	Fewer birds	21
3	Flowers endowed	Fewer birds	12
4	Birds endowed	Fewer flowers	8

On the right side of the window, a 'Welcome to JASP!' message is displayed, including the version number 0.7.5.5 and a brief introduction to the software.

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Hi and welcome to JASP, a fresh and new way to do statistics that we're sure you'll like.

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Also remember, this is an early preview release and there are a number of features missing. So if it doesn't do all you need today, then check back tomorrow; JASP is being developed at break-neck speed!

## 2. Choose "Bayesian Contingency Tables"

The screenshot shows the ContingencyOri software interface. The 'Common' tab is selected, and the 'BF from t' icon is active. The 'Results' panel on the right displays the following:

### Bayesian Contingency Tables

Bayesian Contingency Tables		
	.	
	.	Total
.	.	.
.	.	.
Total	.	.

### Bayesian Contingency Tables Tests

Bayesian Contingency Tables Tests	
	Value
BF <sub>10</sub> joint multinomial	.
N	.

### 3. Choose right analysis

The screenshot shows the 'ContingencyOri\*' software interface. The 'Common' tab is active, displaying several analysis options: Descriptives, T-Tests, ANOVA, Regression, Frequencies, and BF from t. On the left, a list of variables includes 'Endowed', 'Perceived', and 'Count'. The central area contains fields for 'Rows', 'Columns', 'Counts', and 'Layers' (currently showing 'Layer 1'). An 'OK' button is visible next to the 'Rows' field. At the bottom, a 'Statistics' dropdown menu is highlighted with a red box, and an 'Options' dropdown is partially visible below it.

**Results**

**Bayesian Contingency Tables**

Bayesian Contingency Tables

		Total
.	.	.
.	.	.
Total	.	.

**Bayesian Contingency Tables Tests**

	Value
BF <sub>10</sub> joint multinomial	.
N	.

### 3. Choose right analysis

The screenshot shows the 'ContingencyOri\*' software interface. The 'Statistics' tab is active, and the 'Indep. multinomial, rows fixed' option is selected and highlighted with a red box. Other options include Poisson, Joint multinomial, and Hypergeometric (2x2 only). The 'Hypothesis' section has 'Group one ≠ Group two' selected. The 'Bayes Factor' section has 'BF<sub>10</sub>' selected. The 'Additional Statistics' section has 'Log odds ratio (2x2 only)' and 'Cramer's V' selected. The 'Plots' section has 'Log odds ratio (2x2 only)' and 'Cramer's V' selected. The 'Prior' section has 'Prior concentration' set to 1. The 'Results' panel on the right shows the 'Bayesian Contingency Tables' and 'Bayesian Contingency Tables Tests' sections.

**Statistics** OK

**Sampling**

- Poisson
- Joint multinomial
- Indep. multinomial, rows fixed**
- Indep. multinomial, columns fixed
- Hypergeometric (2x2 only)

**Hypothesis**

- Group one ≠ Group two**
- Group one > Group two
- Group one < Group two

**Bayes Factor**

- BF<sub>10</sub>**
- BF<sub>01</sub>
- Log(BF<sub>10</sub>)

**Additional Statistics**

- Log odds ratio (2x2 only)  
Credible interval  %
- Cramer's V**  
Credible interval  %

**Plots**

- Log odds ratio (2x2 only)
- Additional info
- Cramer's V**

**Prior**

Prior concentration

**Results**

**Bayesian Contingency Tables**

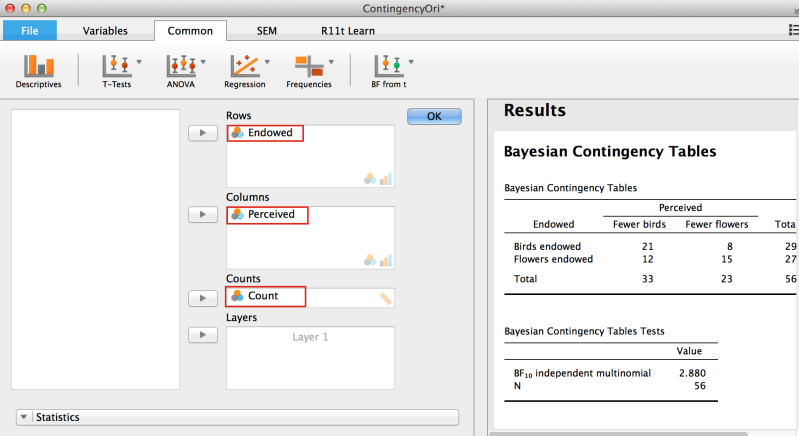
Bayesian Contingency Tables

		Total
.	.	.
.	.	.
Total	.	.

**Bayesian Contingency Tables Tests**

	Value
BF <sub>10</sub> independent multinomial	.
N	.

## 4. Fill in table



The screenshot shows the 'ContingencyOri\*' software interface. The 'Common' tab is active, and the following variables are selected:

- Rows: Endowed
- Columns: Perceived
- Counts: Count
- Layers: Layer 1

The 'Results' panel displays the following Bayesian Contingency Table:

	Perceived		Total
	Endowed	Fewer birds Fewer flowers	
Birds endowed	21	8	29
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Total	33	23	56

Below the table, the Bayesian Contingency Tables Tests are shown:

	Value
BF <sub>10</sub> independent multinomial	2.880
N	56

## 5. Write down result

The screenshot shows the 'ContingencyOri\*' software interface. The 'Results' panel displays the following data:

### Bayesian Contingency Tables

Bayesian Contingency Tables

	Perceived		Total
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### Bayesian Contingency Tables Tests

	Value
<b>BF<sub>10</sub> independent multinomial</b>	<b>2.880</b>
N	56

# Calculate

- Combined data:  $\text{BF}_{10}(d_{\text{orig}}, d_{\text{rep}}) = 0.298$
- Original data:  $\text{BF}_{10}(d_{\text{orig}}) = 2.880$

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- Calculate replication Bayes factor

$$\text{BF}_{10}(d_{\text{rep}} | d_{\text{orig}}) = \frac{0.298}{2.880} \approx 0.10 \quad (5)$$



# Calculate

- Combined data:  $\text{BF}_{10}(d_{\text{orig}}, d_{\text{rep}}) = 0.298$
- Original data:  $\text{BF}_{10}(d_{\text{orig}}) = 2.880$
- Calculate replication Bayes factor

$$\text{BF}_{10}(d_{\text{rep}} | d_{\text{orig}}) = \frac{0.298}{2.880} \approx 0.10 \quad (5)$$

- Thus,

$$\text{BF}_{01}(d_{\text{rep}} | d_{\text{orig}}) = \frac{1}{\text{BF}_{10}(d_{\text{rep}} | d_{\text{orig}})} \approx 9.6 \quad (6)$$

in favour of the null.

## Conclusion and future endeavours

- You can already calculate replication Bayes factors in JASP.

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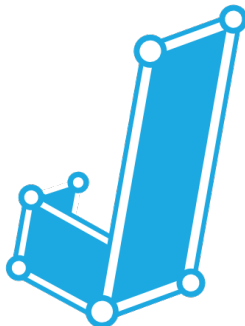
## Conclusion and future endeavours

- You can already calculate replication Bayes factors in JASP.
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## Conclusion and future endeavours

- You can already calculate replication Bayes factors in JASP.
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- Requires full data: Social problem (**publish raw data**).
- Replication Bayes factors depend on the (quality) of the data (**pre-registration**).
- We need to automatise the calculation and develop an interface for this.

# Workshop



Theory and Practice of Bayesian Hypothesis Testing  
A JASP Workshop, August 22–23, 2016 Amsterdam  
<https://jasp-stats.org>