Modality effects on false memory

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Abstract

How does modality of presentation affect the likelihood of real and false memory? A preliminary analysis of the class data for the first experiment.

In the experiment from last week, we were interested in the effect of presentation modality and active recall on subsequent recognition of presented (real) and not presented (attractive foils) words. Some of the following analyses are done to show how to do different means of data presentation and analysis, others are done to help you write your paper on the study. All of the analyses and graphics are done using the R statistical language, some of them make use of the `psych` package.

Data entry

The data are stored on a web server and may be accessed from there using the `read.table` function. After reading the data, it useful to check the dimensions of the data and then to get basic descriptive statistics (Table 1). Before doing any analysis that requires the *psych* package, it is necessary to make it available by using the `library` command. This is shown in Table 1.

These descriptive statistics are partly useful to check the data. In particular, are the minimum and maximum values within acceptable values? They are also useful to get a general feel of the data. However, graphic summaries of them are probably more useful.

Serial position effects

If the subjects followed instructions, we would expect that the recall data will show a serial position effect. That is, that the first part and last part of the list will show greater recall than the middle parts. We can show this by using the `error.bars` function for the first 15 variables. In addition, there were a few false memory (intrusions). These of course

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Table 1: Descriptive statistics for all of the memory data.

```
> library(psych)
> file.url <- "http://personality-project.org/revelle/syllabi/205/memory.data.txt"
> memory <- read.table(file = file.url, header = TRUE)
> dim(memory)

[1] 24 29

> describe(memory)
```

	var	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
p1	1	24	7.08	0.97	7.0	7.20	1.48	5	8	3	-0.70	-0.68	0.20
P2	2	24	6.62	1.17	6.0	6.70	1.48	4	8	4	-0.21	-0.98	0.24
p3	3	24	6.58	1.06	7.0	6.60	1.48	5	8	3	-0.21	-1.27	0.22
p4	4	24	6.04	1.43	6.0	6.10	1.48	3	8	5	-0.33	-0.94	0.29
p5	5	24	5.67	1.27	6.0	5.70	1.48	3	8	5	-0.24	-0.93	0.26
p6	6	24	5.46	1.79	6.0	5.60	1.48	1	8	7	-0.80	-0.07	0.37
p7	7	24	5.00	1.84	5.0	5.15	1.48	1	8	7	-0.60	-0.24	0.38
p8	8	24	4.92	1.64	5.0	5.00	1.48	2	7	5	-0.33	-1.06	0.33
p9	9	24	5.25	1.85	5.0	5.30	1.48	2	8	6	-0.11	-0.87	0.38
p10	10	24	4.62	1.61	4.0	4.60	1.48	2	8	6	0.23	-0.92	0.33
p11	11	24	4.92	1.95	5.0	4.95	2.97	1	8	7	-0.16	-1.00	0.40
p12	12	24	4.79	1.89	5.0	4.80	2.22	1	8	7	-0.08	-1.02	0.39
p13	13	24	5.62	1.66	6.0	5.70	1.48	2	8	6	-0.51	-0.91	0.34
p14	14	24	6.00	1.96	6.0	6.25	1.48	1	8	7	-1.17	0.56	0.40
p15	15	24	6.62	1.47	7.0	6.85	1.48	2	8	6	-1.34	1.85	0.30
total	16	24	85.21	14.33	84.5	86.40	11.12	45	105	60	-0.82	0.56	2.93
Visual	17	24	43.62	7.87	44.5	44.50	7.41	21	55	34	-1.03	0.94	1.61
Aural	18	24	41.58	7.45	41.0	42.35	5.93	24	52	28	-0.74	0.17	1.52
v.foil	19	24	0.25	0.44	0.0	0.20	0.00	0	1	1	1.08	-0.86	0.09
a.foil	20	24	0.67	0.96	0.0	0.50	0.00	0	3	3	1.22	0.31	0.20
total2	21	24	86.12	14.45	86.5	87.40	13.34	45	107	62	-0.89	0.68	2.95
V.rec	22	24	10.33	1.43	11.0	10.45	1.48	7	12	5	-0.48	-0.84	0.29
A.rec	23	24	10.46	1.47	11.0	10.55	1.48	8	12	4	-0.39	-1.43	0.30
V.m	24	24	9.46	2.19	10.0	9.75	1.48	2	12	10	-1.62	3.17	0.45
A.m	25	24	9.46	2.08	9.5	9.65	2.22	4	12	8	-0.67	-0.15	0.43
VF.r	26	24	1.29	0.91	1.0	1.25	0.74	0	3	3	0.44	-0.67	0.19
AF.r	27	24	1.79	1.32	2.0	1.75	1.48	0	4	4	0.15	-1.16	0.27
VF.m	28	24	1.75	1.26	2.0	1.70	1.48	0	4	4	0.33	-0.95	0.26
AF.m	29	24	2.29	1.30	2.0	2.35	1.48	0	4	4	-0.30	-1.04	0.27

do not have a position, and may be graphed as a line towards the bottom of the graph (Figure 1). Another way to graph the data is a boxplot (Figure 2).

Compare the figure to the summary statistics from Table 1. The error bars are just 1.96 * the standard error (se = $\sigma_{\bar{x}}$). The standard error is, in turn, just $\sigma_{\bar{x}} = \sqrt{\frac{\sigma^2}{n}}$

Does modality of presentation affect recall?

Half the lists were presented visually, half aurally. Does this make a difference? This can be found by doing a t-test of the differences between the Aural and Visual recall scores. This is a paired t-test because the same subjects were given both conditions. The appropriate data are in columns 17 and 18. You can specify the variables to test by specifying the columns. They can also be addressed by name using the `with` function. First, we find the means and then do the analysis. We round off the means to 2 decimals.

Both analyses give, of course, the same result. The difference has almost an 8% chance of happening by chance.

Another way to think about a paired t-test is in terms of difference scores. The paired t.test is essentially comparing the mean of each subject's difference between the two conditions to 0 difference. It can also be done by taking these differences and then testing whether the mean difference is different from zero when compared to its standard error. This is done below in Table 3. As would be expected, the results are identical to the prior results. This is an important point to realize. There are frequently different statistics we can use to analyze the data. They appear to be different, but are in fact variations on the central them of a statistic compared to its standard error.

What about the probability of false recall as a function of modality of presentation? This is also just a t-test of difference scores.

This difference of .41 items (across the 16 trials) is unlikely to have happened by chance. That is, it has about a 4% probability of happening by chance. We call a difference of this magnitude a significant difference. The logic of the t-test is described in the accompanying handout.

Although just reporting the means is adequate, it is also useful to give a graphic display of these effects. Convert the scores into percentages (divide by 4*16 for the real recall and divide by 4 for the the false recall) and then plot the results with their standard errors. We create four new variables to do this, put all four into a `data.frame`, and then use `error.bars` to show the results. The t-test takes into account that the data are correlated across trials, and thus, even though the error bars are overlapping, the difference for the foils is significant. This is a problem with using error bars in within subjects designs.

Although in the two condition case, it is typical to do a t-test, it would have been possible to have done an analysis of variance.

It is also interesting to examine the correlation between the four conditions. This may be done in a Scatter Plot Matrix (or SPLOM) plot using the `pairs.panels` function (Figure 4). This figure shows several things at once. The diagonal elements plot the

```
> error.bars(memory[1:15]/8, ylim = c(0, 1), typ = "l", ylab = "percent recalled", xlab = "
+     main = "Recall varies by position")
> intrusions <- mean((memory[19] + memory[20])/8)
> abline(h = intrusions)
> text(8, intrusions + 0.05, "False recall")
```

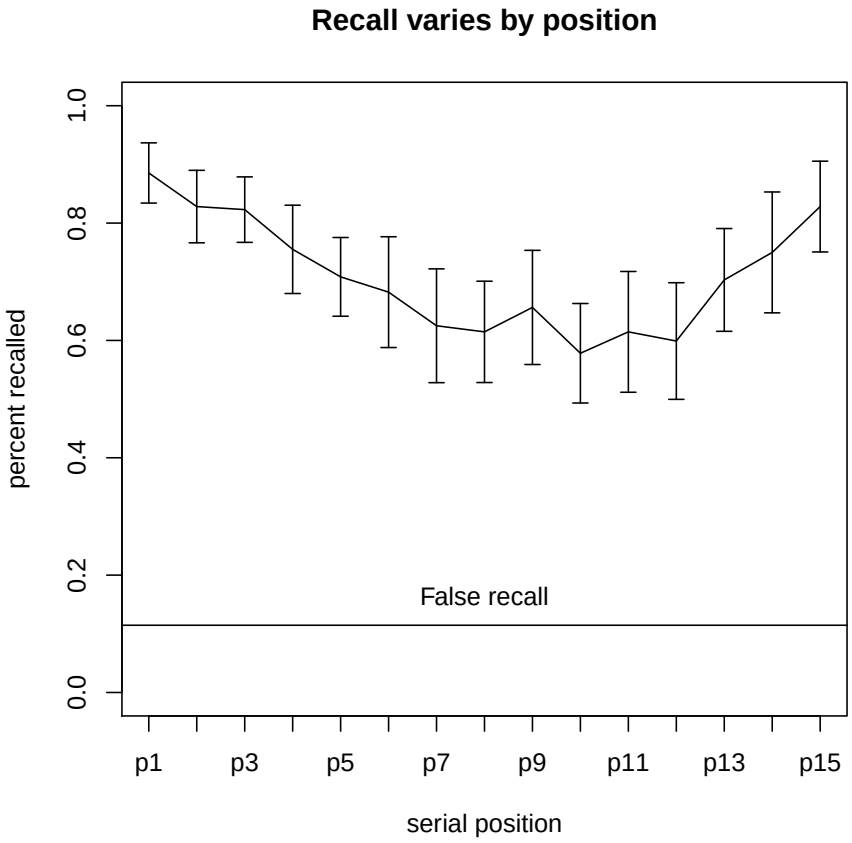

Figure 1. Recall varies by position showing a standard serial position effect. Compare these values to those found in Table 1). The raw numbers have been converted to percentages to allow ease of comparison across studies.

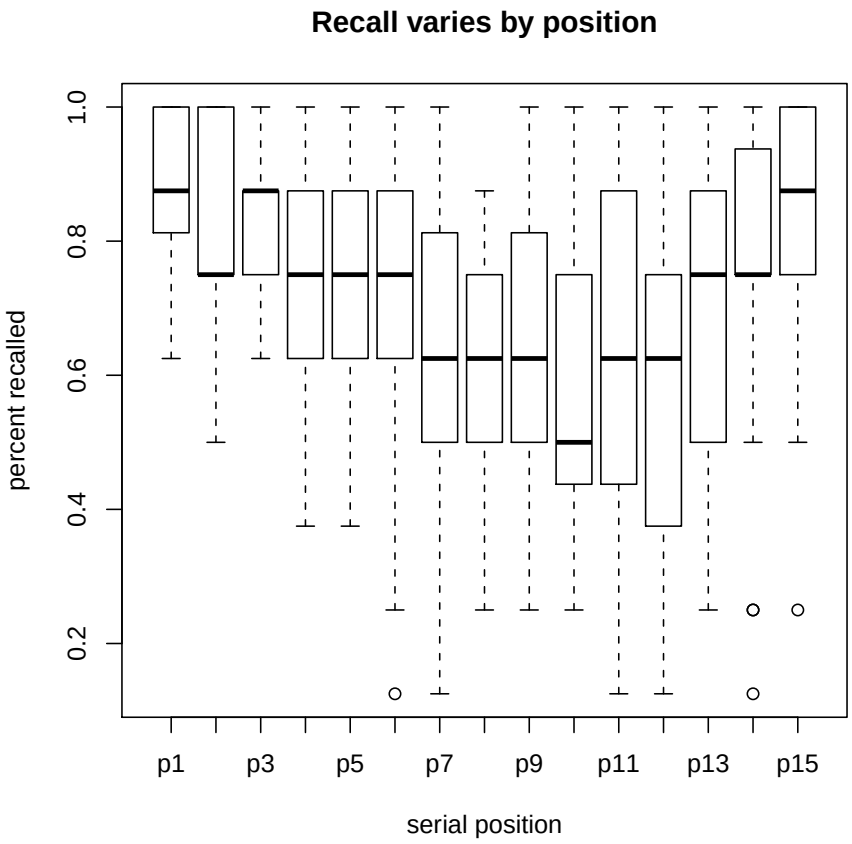

Figure 2. Another way of graphing the data is to do a boxplot. As in Figure 1 the number recalled have been converted to percentages.

Table 2: There are several ways to do a t-test. The variables can be listed by location (they are the 17th and 18th columns) or by names within a data.frame that is made active with the `with` function. Both analyses produce the same results and suggest that the differences in recall between the two modalities has about an 8% chance of happening by chance.

```
> round(mean(memory$Visual), 2)

[1] 43.62

> round(mean(memory$Aural), 2)

[1] 41.58

> t.test(memory[, 17], memory[, 18], paired = TRUE)

        Paired t-test

data:  memory[, 17] and memory[, 18]
t = 1.8491, df = 23, p-value = 0.07734
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.2424231  4.3257564
sample estimates:
mean of the differences
               2.041667

> with(memory, t.test(Visual, Aural, paired = TRUE))

        Paired t-test

data:  Visual and Aural
t = 1.8491, df = 23, p-value = 0.07734
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.2424231  4.3257564
sample estimates:
mean of the differences
               2.041667
```

Table 3: The paired t-test may also be done by taking the differences for each subject and the comparing these differences to 0.

```
> change <- memory$Visual - memory$Aural
> t.test(change)

        One Sample t-test

data:  change
t = 1.8491, df = 23, p-value = 0.07734
alternative hypothesis: true mean is not equal to 0
95 percent confidence interval:
 -0.2424231  4.3257564
sample estimates:
mean of x
 2.041667
```

Table 4: The effect of modality of presentation on false intrusions. There are more intrusions when the stimuli are presented aurally.

```
> round(mean(memory$v.foil), 2)

[1] 0.25

> round(mean(memory$a.foil), 2)

[1] 0.67

> with(memory, t.test(v.foil, a.foil, paired = TRUE))

        Paired t-test

data:  v.foil and a.foil
t = -2.1982, df = 23, p-value = 0.03827
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.80878480 -0.02454853
sample estimates:
mean of the differences
             -0.4166667
```

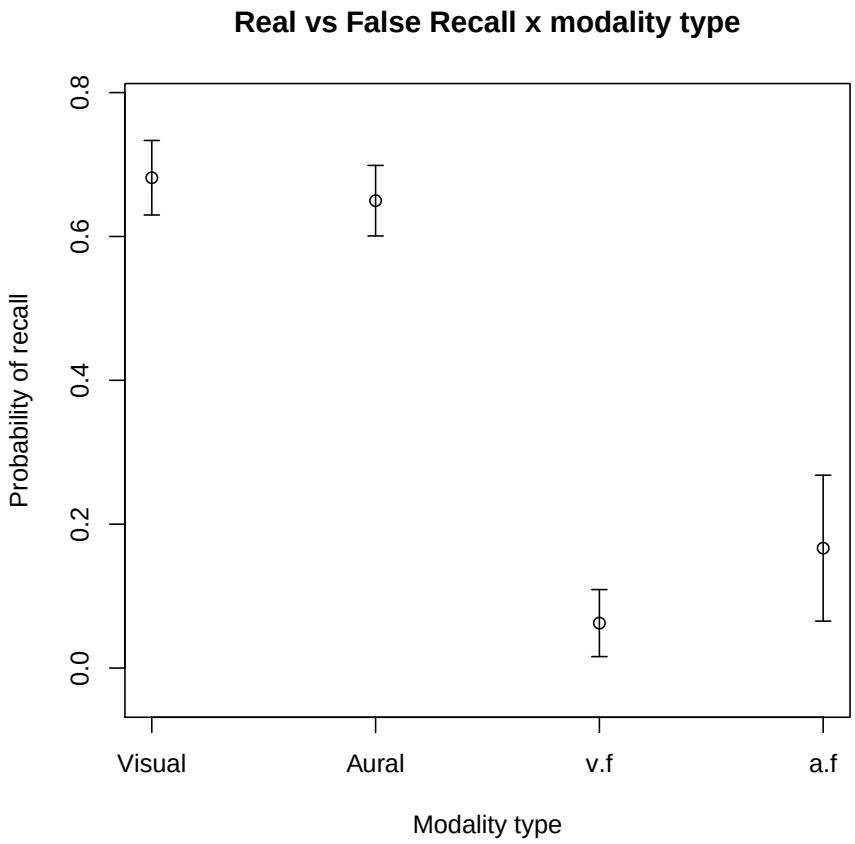

Figure 3. Modality of presentation affects the probability of false but not real recall. Note, however, that aural presentation seems to hurt real recall but increase false recall.

histograms of the data. The panels above the diagonal show the Pearson Product Moment Correlation, the panels below the diagonal show the corresponding scatter plots. What is very clear is that people who are good at remembering the list when presented visually are also good at remembering it when presented aurally. A much smaller effect is the relationship between false recall or intrusion in the two conditions.

t-tests done on percentages rather than total scores

The prior analyses were done on the total scores for the subjects. This makes it hard to compare the recall for the real data versus the incidence of intrusions. This can be corrected by converting the numbers to percentages and then doing the t-test (Table 5). Note how although the means are now different, the values of t and the probabilities remain the same as before.

Analysis of variance of the recall data

It appears from looking at the means that recall of the presented stimuli went down with Aural presentation, but of false stimuli went up with presentation. That is, the shape of the two relationships appears to be different. Is this a reliable difference? This can be tested using Analysis of Variance. The method behind this will be explained in more detail in a later section, but for now just consider the following result (Table 6). This analysis confirms that there is no over all effect of modality, and an extremely large effect for the percent recalled as function of real versus false words. Most importantly, this analysis shows that the pattern of results for the modality effect is different for real versus false words. That is, while visual presentation has the highest probability of correct recall, it has the lowest probability of false recall. Aural presentation has a much higher probability of false recall but a lower probability of real recall. An alternative way of describing this effect is that visual presentation enhances correct recall (recall the reals, don't recall the falses).

Recognition

In addition to the simple recall task, there was a subsequent recognition task, where the subjects where asked to identify whether words had been presented before (old) or whether they had not been presented (new).

There are three experimental variables that can be studied in the recognition data. What is the effect of mode of presentation (Visual versus Aural), what it the effect of having a chance to recall or instead do the math (Recall vs. math) and do these effects differ for recalling real versus false memories (real versus false). Although this could be done in a series of t-tests, it is more appropriate to do this as a within-subjects analysis of variance. To make the analysis a little simpler, first consider just the mode and recall variables.

```
> pairs.panels(recall, main = "Recall by modality")
```

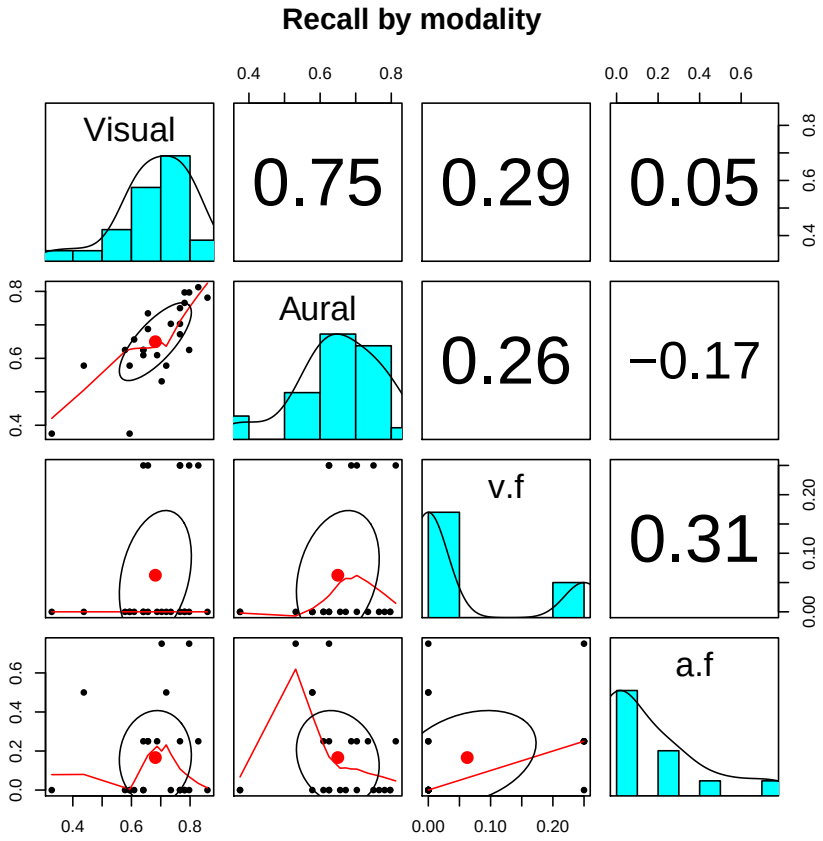

Figure 4. The correlation and scatter plots of the four within subject measures. Visual and Aural are correct recall, v.f and a.f are intrusions in the visual and aural conditions. This figure shows several things at once. The diagonal elements plot the histograms of the data. The panels above the diagonal show the Pearson Product Moment Correlation, the panels below the diagonal show the corresponding scatter plots.

Table 5: default

```
> Visual.p <- memory$Visual/64
> Aural.p <- memory$Aural/64
> t.test(Visual.p, Aural.p, paired = TRUE)

        Paired t-test

data:  Visual.p and Aural.p
t = 1.8491, df = 23, p-value = 0.07734
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.003787861  0.067589944
sample estimates:
mean of the differences
             0.03190104

> mean(Visual.p)

[1] 0.6816406

> mean(Aural.p)

[1] 0.6497396

> v.f = memory$v.foil/4
> a.f = memory$a.foil/4
> t.test(v.f, a.f, paired = TRUE)

        Paired t-test

data:  v.f and a.f
t = -2.1982, df = 23, p-value = 0.03827
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.202196201 -0.006137132
sample estimates:
mean of the differences
             -0.1041667

> mean(v.f)

[1] 0.0625

> mean(a.f)

[1] 0.1666667
```

Table 6: Two way repeated measures analysis of variance of the recall data. This tests three separate hypotheses at the same time: does modality make a difference, does true versus false make a difference, and is there an interaction of true/false with modality. The prior analyses were testing these separately, this analysis tests them together.

```
> nvar <- dim(recall)[2]
> nsub <- dim(recall)[1]
> stacked.recall <- stack(recall)
> recall.df <- data.frame(values = stacked.recall[1], subj = rep(paste("Subj", 1:nsub, sep = ""),
+     nvar), modality = rep(c(rep("Visual", nsub), rep("Aural", nsub)), 2), real.false = c(rep("real",
+     nsub * 2), rep("false", nsub * 2)))
> recall.aov <- aov(values ~ modality * real.false + Error(subj/(modality * real.false)), data = recall.df)
> summary(recall.aov)

Error: subj
          Df  Sum Sq  Mean Sq F value Pr(>F)
Residuals 23 0.83158 0.036156

Error: subj:modality
          Df   Sum Sq  Mean Sq F value Pr(>F)
modality   1 0.031334 0.031334  2.5254 0.1257
Residuals 23 0.285378 0.012408

Error: subj:real.false
           Df Sum Sq Mean Sq F value    Pr(>F)
real.false  1 7.2892  7.2892  226.52 2.131e-13 ***
Residuals  23 0.7401  0.0322
---
Signif. codes:  0 âĂŸ***âĂŹ 0.001 âĂŸ**âĂŹ 0.01 âĂŸ*âĂŹ 0.05 âĂŸ.âĂŹ 0.1 âĂŸ âĂŹ 1

Error: subj:modality:real.false
                   Df  Sum Sq  Mean Sq F value  Pr(>F)
modality:real.false  1 0.11109 0.111087  6.1335 0.02105 *
Residuals           23 0.41656 0.018111
---
Signif. codes:  0 âĂŸ***âĂŹ 0.001 âĂŸ**âĂŹ 0.01 âĂŸ*âĂŹ 0.05 âĂŸ.âĂŹ 0.1 âĂŸ âĂŹ 1

> print(model.tables(recall.aov, "mean"))

Tables of means
Grand mean

0.3901367

 modality
modality
 Aural Visual
0.4082 0.3721

 real.false
real.false
 false   real
0.1146 0.6657

 modality:real.false
        real.false
modality false  real
  Aural  0.1667 0.6497
  Visual 0.0625 0.6816
```

To do this analysis, follow the tutorial at `http://personality-project.org/r/#anova`. The data are in the memory data set and are columns 22 - 25. Lets first specify a few parameter values and then do the analysis. First we need to reorganize the data in a manner suitable for the analysis. This is done using the `stack` function. `stack` takes a 24 *4 data matrix and "strings" it out to be a 96 * 2 matrix. (The extra column is just a variable label). We then create several new label variables to define the conditions. This is not as complicated as looks (trust me!). We do this by creating a `data.frame` containing the stacked data, and columns describing the various conditions as well as the repeated nature of the subjects. Although the web tutorial shows this in one step, it might be easier to understand in several steps.

Just real recognition

```
> numcases <- dim(recall)[1]
> numvariables <- 4
> numlevels1 <- 2
> numlevels2 <- 2
> stackeddata <- stack(memory[22:25])
> subj <- factor(rep(paste("subj", 1:numcases, sep = ""), numvariables))
> modality <- factor(rep(c(rep("Visual", numcases), rep("Aural", numcases)), numvariables/n
> recall.math <- factor(c(rep("recall", numcases * numlevels1), rep("math", numcases * numl
> recog.df <- data.frame(values = stackeddata[1], subj = subj, modality = modality, recall.
> recog.df[c(1:4, 46:50, 92:96), ]

   values   subj modality recall.math
1      12  subj1   Visual      recall
2      11  subj2   Visual      recall
3      11  subj3   Visual      recall
4      10  subj4   Visual      recall
46     12 subj22    Aural      recall
47     12 subj23    Aural      recall
48     11 subj24    Aural      recall
49     11  subj1   Visual        math
50      8  subj2   Visual        math
92      8 subj20    Aural        math
93      6 subj21    Aural        math
94      9 subj22    Aural        math
95     11 subj23    Aural        math
96     12 subj24    Aural        math
```

That wasn't too bad. Now, for the analysis:

```
> recog.aov <- aov(values ~ modality * recall.math + Error(subj/(modality * recall.math)),
> summary(recog.aov)

Error: subj
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals 23 177.74  7.7278

Error: subj:modality
          Df  Sum Sq Mean Sq F value Pr(>F)
modality   1  0.0937 0.09375  0.0857 0.7723
Residuals 23 25.1563 1.09375

Error: subj:recall.math
            Df Sum Sq Mean Sq F value  Pr(>F)
recall.math  1 21.094 21.0938  7.5621 0.01141 *
Residuals   23 64.156  2.7894
---
Signif. codes:  0 âĂŸ***âĂŹ 0.001 âĂŸ**âĂŹ 0.01 âĂŸ*âĂŹ 0.05 âĂŸ.âĂŹ 0.1 âĂŸ âĂŹ 1

Error: subj:modality:recall.math
                     Df Sum Sq Mean Sq F value Pr(>F)
modality:recall.math  1  0.094 0.09375  0.0537 0.8188
Residuals            23 40.156 1.74592

> print(model.tables(recog.aov, "means"), digits = 3)

Tables of means
Grand mean

9.927083

 modality
modality
 Aural Visual
  9.96   9.90

 recall.math
recall.math
  math recall
  9.46  10.40

 modality:recall.math
```

```
        recall.math
modality math  recall
  Aural   9.46 10.46
  Visual  9.46 10.33
```

What does this mean? It shows that although there was only a trivial difference in recognition as a function of modality of presentation, there was a reliable (statistically significant) difference of almost 1 point in whether or not the subjects did math or recall following the list. A difference this large has about a 1% probability of happening if there were no real difference in the population.

Do the same thing for the false recognition

But what about false recognition? Do the same effects hold? Do the same analysis of variance.

```
> stackedfalse <- stack(memory[26:29])
> false.df <- data.frame(values <- stackedfalse[1], subj = subj, modality = modality, recal
> false.aov <- aov(values ~ modality * recall.math + Error(subj/(modality * recall.math)),
> summary(false.aov)

Error: subj
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals 23 78.656  3.4198

Error: subj:modality
          Df  Sum Sq Mean Sq F value  Pr(>F)
modality   1  6.5104  6.5104    7.22 0.01316 *
Residuals 23 20.7396  0.9017
---
Signif. codes:  0 âĂŸ***âĂŹ 0.001 âĂŸ**âĂŹ 0.01 âĂŸ*âĂŹ 0.05 âĂŸ.âĂŹ 0.1 âĂŸ âĂŹ 1

Error: subj:recall.math
            Df  Sum Sq Mean Sq F value  Pr(>F)
recall.math  1  5.5104  5.5104  4.7398 0.03999 *
Residuals   23 26.7396  1.1626
---
Signif. codes:  0 âĂŸ***âĂŹ 0.001 âĂŸ**âĂŹ 0.01 âĂŸ*âĂŹ 0.05 âĂŸ.âĂŹ 0.1 âĂŸ âĂŹ 1

Error: subj:modality:recall.math
                     Df Sum Sq Mean Sq F value Pr(>F)
modality:recall.math  1 0.0104 0.01042  0.0291 0.8661
Residuals            23 8.2396 0.35824
```

```
> print(model.tables(false.aov, "means"))

Tables of means
Grand mean

1.78125

 modality
modality
 Aural Visual
2.0417 1.5208

 recall.math
recall.math
  math recall
2.0208 1.5417

 modality:recall.math
        recall.math
modality math   recall
  Aural  2.2917 1.7917
  Visual 1.7500 1.2917
```

Here we find that there are reliably more false recognitions following Aural presentations rather than Visual, and more for words presented without the chance to recall (the math condition versus the recall condition). These two effects do not interact with each other, however. That is to say, that the false recognition was just an additive function of modality and condition. Subjects did best (fewest false recognitions) if they saw the target words and had a chance to recall them. They did worst if the heard them and did not have a chance to recall them.

Rescale the data to be in percentages rather than raw numbers

The prior analyses on recognition were done with the raw numbers. It is perhaps more useful to express them in terms of percent possible for each condition. This just requires dividing by the number possible in each condition. For the correct recognition, there were 3 words to be recognized in each trial and 4 trials in each condition. Thus, we divide the numbers by 12. For the false recognition, there were just 1 word to be falsely recognized and 4 trials per condition. Thus we divide the numbers by 4.

```
> recog.df[1] <- recog.df[1]/12
> recog.aov <- aov(values ~ modality * recall.math + Error(subj/(modality * recall.math)),
> summary(recog.aov)
```

```
Error: subj
          Df Sum Sq  Mean Sq F value Pr(>F)
Residuals 23 1.2343 0.053665

Error: subj:modality
          Df   Sum Sq   Mean Sq F value Pr(>F)
modality   1 0.000651 0.0006510  0.0857 0.7723
Residuals 23 0.174696 0.0075955

Error: subj:recall.math
            Df  Sum Sq  Mean Sq F value  Pr(>F)
recall.math  1 0.14648 0.146484  7.5621 0.01141 *
Residuals   23 0.44553 0.019371
---
Signif. codes:  0 âĂŸ***âĂŹ 0.001 âĂŸ**âĂŹ 0.01 âĂŸ*âĂŹ 0.05 âĂŸ.âĂŹ 0.1 âĂŸ âĂŹ 1

Error: subj:modality:recall.math
                     Df   Sum Sq  Mean Sq F value Pr(>F)
modality:recall.math  1 0.000651 0.000651  0.0537 0.8188
Residuals            23 0.278863 0.012124

> print(model.tables(recog.aov, "means"), digits = 3)

Tables of means
Grand mean

0.827257

 modality
modality
 Aural Visual
 0.830  0.825

 recall.math
recall.math
  math recall
 0.788  0.866

 modality:recall.math
        recall.math
modality math  recall
```

```
  Aural  0.788 0.872
  Visual 0.788 0.861

> false.df[1] <- false.df[1]/4
> false.aov <- aov(values ~ modality * recall.math + Error(subj/(modality * recall.math)),
> summary(false.aov)

Error: subj
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals 23  4.916 0.21374

Error: subj:modality
          Df Sum Sq Mean Sq F value  Pr(>F)
modality   1 0.4069 0.40690    7.22 0.01316 *
Residuals 23 1.2962 0.05636
---
Signif. codes:  0 âĂŸ***âĂŹ 0.001 âĂŸ**âĂŹ 0.01 âĂŸ*âĂŹ 0.05 âĂŸ.âĂŹ 0.1 âĂŸ âĂŹ 1

Error: subj:recall.math
            Df Sum Sq Mean Sq F value  Pr(>F)
recall.math  1 0.3444 0.34440  4.7398 0.03999 *
Residuals   23 1.6712 0.07266
---
Signif. codes:  0 âĂŸ***âĂŹ 0.001 âĂŸ**âĂŹ 0.01 âĂŸ*âĂŹ 0.05 âĂŸ.âĂŹ 0.1 âĂŸ âĂŹ 1

Error: subj:modality:recall.math
                     Df  Sum Sq  Mean Sq F value Pr(>F)
modality:recall.math  1 0.00065 0.000651  0.0291 0.8661
Residuals            23 0.51497 0.022390

> print(model.tables(false.aov, "means"))

Tables of means
Grand mean

0.4453125

 modality
modality
 Aural Visual
0.5104 0.3802
```

```
 recall.math
recall.math
  math recall
0.5052 0.3854

 modality:recall.math
        recall.math
modality math   recall
  Aural  0.5729 0.4479
  Visual 0.4375 0.3229
```

Several things to notice from this analysis. Although the means are very different, the analysis of variances have not changed. Secondly, note how large the probability of false recognitions are (44% overall).

Compare patterns for real versus false recognition

Just as we were able to look at two variables and their interactions at one time, so it is possible to see if the effects of modality, recall/math, and true/false interact with each other. This is yet one more analysis of variance. We do this by combining the two previous data frames into one and then adding one more column to label whether the data are true or false recognitions.

This is a lot of output and shows that recall vs. math makes a differece, true/false makes an enormous differences, and that recall/math interacts with true/false. Lets look at the means to see what the pattern looks like (this is the same as combining the two previous tables of means).

All of this might be easier to understand if we look at a graphic of the 8 cells. From this graph, it seems as if what makes true recognition go down makes false recognition go up.

Table 7: A three way analysis of variance within subjects examines the effects of three variables and their interactions in one analysis.

```
> all.recog <- rbind(recog.df, false.df)
> all.recog <- data.frame(all.recog, tf = c(rep("true", 96), rep("false", 96)))
> all.aov <- aov(values ~ modality * recall.math * tf + Error(subj/(modality * recall.math * tf)),
+     data = all.recog)
> summary(all.aov)

Error: subj
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals 23 3.2516 0.14137

Error: subj:modality
          Df  Sum Sq  Mean Sq F value  Pr(>F)
modality   1 0.22005 0.220052  7.0374 0.01422 *
Residuals 23 0.71918 0.031269
---
Signif. codes:  0 âĂŸ***âĂŹ 0.001 âĂŸ**âĂŹ 0.01 âĂŸ*âĂŹ 0.05 âĂŸ.âĂŹ 0.1 âĂŸ âĂŹ 1

Error: subj:recall.math
            Df  Sum Sq  Mean Sq F value Pr(>F)
recall.math  1 0.02083 0.020833  0.3893 0.5388
Residuals   23 1.23090 0.053518

Error: subj:tf
          Df Sum Sq Mean Sq F value    Pr(>F)
tf         1 7.0023  7.0023   55.56 1.412e-07 ***
Residuals 23 2.8987  0.1260
---
Signif. codes:  0 âĂŸ***âĂŹ 0.001 âĂŸ**âĂŹ 0.01 âĂŸ*âĂŹ 0.05 âĂŸ.âĂŹ 0.1 âĂŸ âĂŹ 1

Error: subj:modality:recall.math
                    Df  Sum Sq  Mean Sq   F value Pr(>F)
modality:recall.math  1 0.00000 0.000000 1.751e-29      1
Residuals            23 0.51215 0.022267

Error: subj:modality:tf
            Df  Sum Sq  Mean Sq F value  Pr(>F)
modality:tf  1 0.18750 0.187500  5.7367 0.02515 *
Residuals   23 0.75174 0.032684
---
Signif. codes:  0 âĂŸ***âĂŹ 0.001 âĂŸ**âĂŹ 0.01 âĂŸ*âĂŹ 0.05 âĂŸ.âĂŹ 0.1 âĂŸ âĂŹ 1

Error: subj:recall.math:tf
               Df  Sum Sq Mean Sq F value   Pr(>F)
recall.math:tf  1 0.47005 0.47005  12.204 0.001959 **
Residuals      23 0.88585 0.03852
---
Signif. codes:  0 âĂŸ***âĂŹ 0.001 âĂŸ**âĂŹ 0.01 âĂŸ*âĂŹ 0.05 âĂŸ.âĂŹ 0.1 âĂŸ âĂŹ 1

Error: subj:modality:recall.math:tf
                        Df   Sum Sq   Mean Sq F value Pr(>F)
modality:recall.math:tf  1 0.001302 0.0013021  0.1063 0.7473
Residuals               23 0.281684 0.0122471
```

Table 8: The cell means for the three way anova.

```
> print(model.tables(all.aov, "means"))

Tables of means
Grand mean

0.6362847

 modality
modality
 Aural Visual
0.6701 0.6024

 recall.math
recall.math
  math recall
0.6467 0.6259

 tf
tf
 false   true
0.4453 0.8273

 modality:recall.math
       recall.math
modality math   recall
  Aural  0.6806 0.6597
  Visual 0.6128 0.5920

 modality:tf
       tf
modality false  true
  Aural  0.5104 0.8299
  Visual 0.3802 0.8247

 recall.math:tf
           tf
recall.math false  true
     math   0.5052 0.7882
     recall 0.3854 0.8663

 modality:recall.math:tf
, , tf = false

       recall.math
modality math   recall
  Aural  0.5729 0.4479
  Visual 0.4375 0.3229

, , tf = true

       recall.math
modality math   recall
  Aural  0.7882 0.8715
  Visual 0.7882 0.8611
```

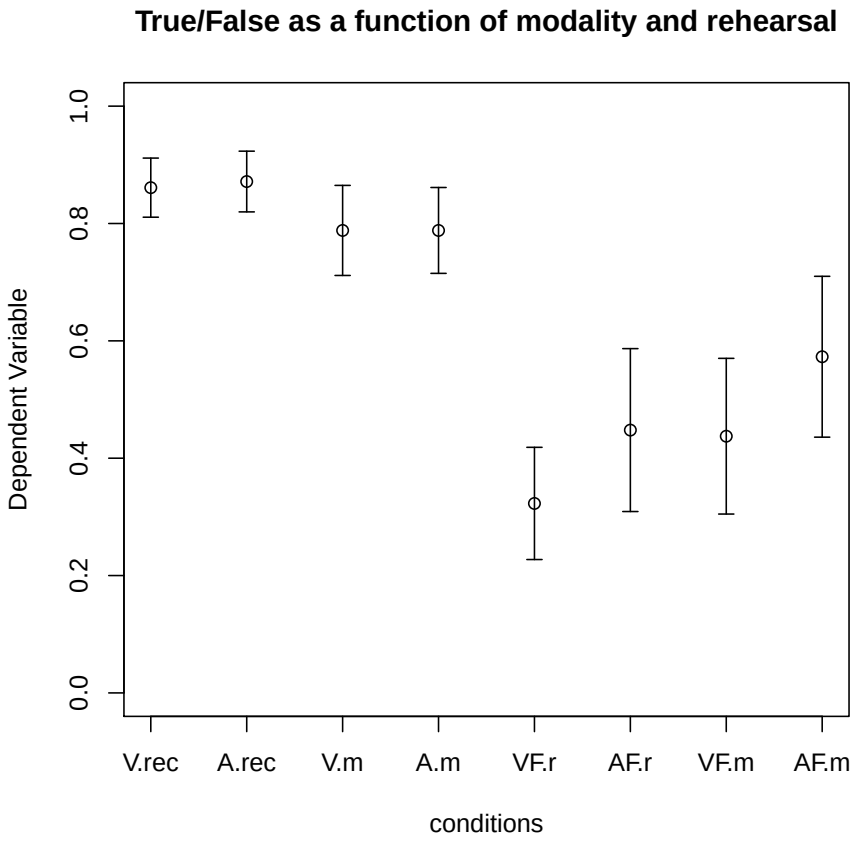

Figure 5. Correct and False recognition memory as a function of modality of presentation and of rehearsal. V/A represent Visual versus Aural presentation, rec/m represent recall or math, F indicates false recognition. Error bars are overestimates of within cell error in a repeated measures design