ANOVA for Sensory Data

Visual Analysis by PanelCheck

- From simple to 3-way mixed ANOVA
  - Designing a simle experiment
  - Simple two-way analysis and simple t-test
  - Two-way with reps analysis
  - Random effect in two-way
  - Mixed 3-way ANOVA analysis
  - Using PanelCheck

Twoway ANOVA (without replication)

Sweet	ProdA	ProdB	ProdC	ProdD
Pan.1	6	3	10	7
Pan.2	8	5	9	6
Pan.3	10	8	9	6
Pan.4	7	4	8	6

Twoway ANOVA (without replication)

Source	DF	SS	MS	F	Prob
Assessor	3	9.5	3.17	1.78	0.2206
Product	3	12.5	12.17	6.84	0.0107
Residual	9	16	1.78		

Low P-values: Variability is unlikely high – so there MUST be a real difference!

- Assessors are NOT significantly different!
- Products ARE different!

WHAT IF ONLY 2 PRODUCTS? (and e.g. 10 Assessors)

Product1 1.6 0.9 2.4 2.8 5.3 3.6 5.6 4.1 5.8 10.1
Product2 4.6 1.4 5.4 5.6 4.9 7.3 5.5 7.3 9.4 10.1

Diff, D 3.0 0.5 3.0 2.8 -0.4 3.7 -0.1 3.2 3.6 0.0

Paired t-test: (in R)

> mean(dif)/(sd(dif/sqrt(10)))
[1] 3.597661

$$t = \frac{\overline{D}}{s_D/\sqrt{n}}$$

The square of the paired t-test:
> (mean(dif)/(sd(dif/sqrt(10))))^2
[1] 12.94317

$$t^2 = F$$

WHAT IF ONLY 2 PRODUCTS? (and e.g. 10 Assessors)

Product1 1.6 0.9 2.4 2.8 5.3 3.6 5.6 4.1 5.8 10.1
Product2 4.6 1.4 5.4 5.6 4.9 7.3 5.5 7.3 9.4 10.1

Diff, D 3.0 0.5 3.0 2.8 -0.4 3.7 -0.1 3.2 3.6 0.0

> anova(lm(Sweetness~Assessor+Product))
Analysis of Variance Table

Response: Sweetness

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Assessor	9	107.430	11.9367	8.2955	0.002110 **
Product	1	18.625	18.6245	12.9432	0.005769 **
Residuals	9	12.950	1.4389		

Twoway ANOVA (without replication)

2-way ANOVA =

”multi-product paired t-testing”

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Twoway ANOVA (without replication)
Post hoc Analysis
(t-testing with ALL/Pooled error info)

$$LSD = t_{0.975}(9)\sqrt{2MSE/4}$$
$$= 2.262\sqrt{2\times 1.78/4}$$
$$= 2.13$$

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Twoway ANOVA (with randomized replications)

	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	Sample G
Assessor 1	1,0 1,5	7,8 8,0	7,4 7,2	3,1 2,3	3,8 4,0	8,3 9,0	6,3 6,0
Assessor 2	1,3 1,1	8,8 9,0	8,9 8,5	4,1 4,0	1,7 2,0	6,5 7,0	4,5 5,0
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Assessor 4	1,3 1,1	8,0 9,0	8,9 7,9	3,7 4,0	1,8 2,0	6,7 7,0	5,5 5,0
Assessor 5	6,0 5,8	5,5 6,0	3,0 3,3	5,5 6,0	7,8 8,0	8,7 8,8	1,8 2,0
Assessor 6	6,3 6,0	6,5 6,0	3,2 3,0	5,8 6,0	7,8 8,0	8,9 8,8	1,9 2,0

For analysing randomized replicated data for a panel!
(Completely randomized 2-way experiment)

Twoway ANOVA (with replication)

Source	DF	SS	MS	F	Prob
Assessor	5	4.162	0.832	8.4345	0.00014
Product	6	272.085	45.347	459.491	<0.00001
Assessor* Product	30	280.255	9.342	94.6581	<0.00001
Residual	42	4.145	0.099		

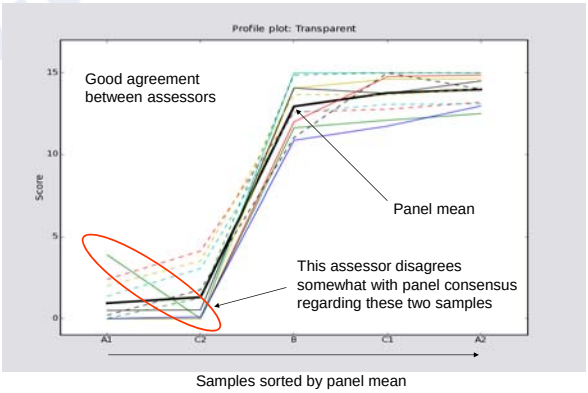
Interaction

- Degree of non-parallel structure in profile plot:
  - Different use of scale
  - Disagreements
  - Noise

PROFILE PLOT - How does it work?

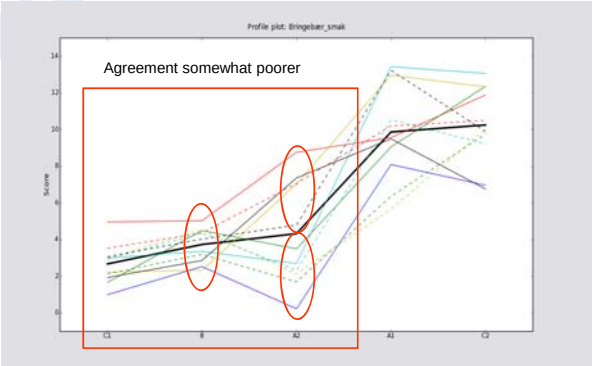
- Results are based on individual and consensus sample scoring and ranking
- X-axis: consensus sample ranking (low to high intensity)
- Y-axis: score value for sample
- Shows one line for each assessor + one consensus line

PROFILE PLOT



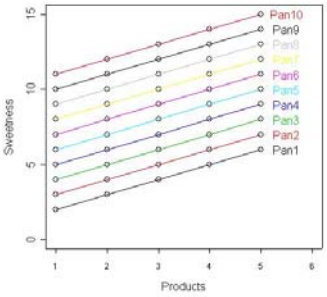
Samples sorted by panel mean

PROFILE PLOT



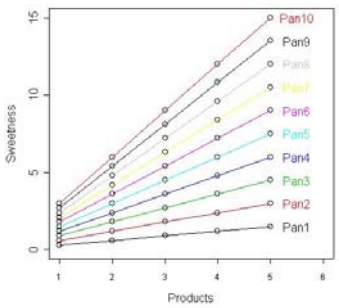
PROFILE PLOT:

Idealized NO interaction
between products and panelists



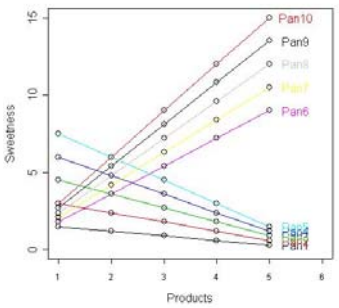
PROFILE PLOT:

Idealized (scale) interaction
between products and panelists



PROFILE PLOT:

Idealized(scale AND cross over)
interaction between products and panelists



IF Siginificant interaction:

Product conclusions depend on assessor!

- Classical fixed ANOVA approach:
  - Tell the product story "by assessor"! (Profile plot)
- Most often in sensory:
  - Focus on product main (average) effects!
  - Question: Are they meaningful/reproducable across assessors?
  - How to answer: Use mixed model! (Consider assessors as a RANDOM sample)

Twoway ANOVA (with replication)

Source	DF	SS	MS	F	Prob
Assessor	5	4.162	0.832	8.4345	0.00014
Product	6	272.085	45.347	459.491	<0.00001
Assessor* Product	30	280.255	9.342	94.6581	<0.00001
Residual	42	4.145	0.099		

The F-test for product difference given in this table is NOT to be used!

Problems of this test:
• Does not take the "error" due to the interactions properly into account

• A small average product difference may be called significant even though there is a large Assessor x Product interaction

Twoway ANOVA MIXED approach:

Source	DF	SS	MS	F	Prob
Assessor	5	4.162	0.832	8.4345	0.00014
Product	6	272.085	45.347	459.491	<0.00001
Assessor* Product	30	280.255	9.342	94.6581	<0.00001
Residual	42	4.145	0.099		

$$F = \frac{MS_{Product}}{MS_{Assessor*Product}} = \frac{45.347}{9.342} = 4.85$$

Twoway ANOVA (with replication) Post hoc Analysis

$$LSD = t_{0.975}(30)\sqrt{2MS_{Assessor*Product}/12}$$

Summarize product average differences ("as usual")

Twoway ANOVA (with randomized replications)

	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	Sample G
Assessor 1	1,0 1,5	7,8 8,0	7,4 7,2	3,1 2,3	3,8 4,0	8,3 9,0	6,3 6,0
Assessor 2	1,3 1,1	8,8 9,0	8,9 8,5	4,1 4,0	1,7 2,0	6,5 7,0	4,5 5,0
Assessor 3	1,0 1,2	7,5 8,0	7,4 6,8	2,6 2,3	3,6 4,0	8,0 9,0	5,5 6,0
Assessor 4	1,3 1,1	8,0 9,0	8,9 7,9	3,7 4,0	1,8 2,0	6,7 7,0	5,5 5,0
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Assessor 6	6,3 6,0	6,5 6,0	3,2 3,0	5,8 6,0	7,8 8,0	8,9 8,8	1,9 2,0

For analysing randomized replicated data for a panel!
(Completely randomized 2-way experiment)

Mixed 2-way = Analysing average data

	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	Sample G
Assessor 1	1,0 1,5	7,8 8,0	7,4 7,2	3,1 2,3	3,8 4,0	8,3 9,0	6,3 6,0
Assessor 2	1,3 1,1	8,8 9,0	8,9 8,5	4,1 4,0	1,7 2,0	6,5 7,0	4,5 5,0
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Assessor 6	6,3 6,0	6,5 6,0	3,2 3,0	5,8 6,0	7,8 8,0	8,9 8,8	1,9 2,0

Average data = two-way WITHOUT Replication

	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	Sample G
Assessor 1	1,25	7,9	7,3	2,7	3,9	8,65	6,15
Assessor 2	1,2	8,9	8,7	4,05	1,85	6,75	4,75
Assessor 3	1,1	7,75	7,1	2,45	3,8	8,5	5,75
Assessor 4	1,2	8,5	8,4	3,85	1,9	6,85	5,25
Assessor 5	5,9	5,75	3,15	5,75	7,9	8,75	1,9
Assessor 6	6,15	6,25	3,1	5,9	7,9	8,85	1,95

Mixed 2-way = Analysing average data

	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	Sample G
Assessor 1	1,0 1,5	7,8 8,0	7,4 7,2	3,1 2,3	3,8 4,0	8,3 9,0	6,3 6,0
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Twoway ANOVA (with replication)

Source	DF	SS	MS	F	Prob
Assessor	5	4.162	0.832	8.4345	[illegible]
Product	6	272.085	45.347	459.491	[illegible]
Assessor* Product	30	280.255	9.342	94.6581	<0.00001
Residual	42	4.145	0.099		

$$F = \frac{MS_{Product}}{MS_{Assessor*Product}} = \frac{45.347}{9.342} = 4.85$$

Conclusion on two-way ANOVA:

- Averaging (randomized) replicates makes sense!
- For more general situations (eg. with missing values):
  - Using the random effect assumption in a mixed model for the complete data is a better approach.
- An what if replications are organized in sessions?
  - Averaging still equivalent to random assessor effect
  - BUT: this would ignore possible session-by-product interactions!

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Twoway ANOVA (with session replication)

Sess1	SamA	SamB	SamC	SamD
Ass1	1,0	8,0	7,4	2,3
Ass2	1,3	9,0	8,9	4,0
Ass3	1,0	8,0	7,4	2,3
Ass4	1,3	9,0	8,9	4,0
Ass5	6,0	6,0	3,0	6,0
Ass6	6,0	6,0	3,0	6,0

Sess2	SamA	SamB	SamC	SamD
Ass1	1,0	8,0	7,4	2,3
Ass2	1,3	9,0	8,9	4,0
Ass3	1,0	8,0	7,4	2,3
Ass4	1,3	9,0	8,9	4,0
Ass5	6,0	6,0	3,0	6,0
Ass6	6,0	6,0	3,0	6,0

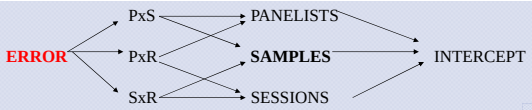
For analysing replicated data for a panel using sessions!

3-way ANOVA: Session (R), Assessor (P), Samples (S)

Analysis of the typical sensory data set

- Panelists (P)
- Samples (S)
- Session (R)

- **Simple 3-way ANOVA for each variable:**



Main issue: Test for product differences: (as given by standard Fixed ANOVA software – NOT to be used!)

$$F = \frac{MS_{Sample}}{MS_{Error}}$$

Threeway ANOVA

Source	DF	SS	MS	F	Prob
Panellist (P)	5			NOT OK	NOT OK
Sample (S)	3			NOT OK	NOT OK
Session (R)	1			NOT OK	NOT OK
Pan*Sam	15			OK!!	OK!!
Sam*Ses	3			OK!!	OK!!
Pan*Ses	5			OK!!	OK!!
Residual	15				

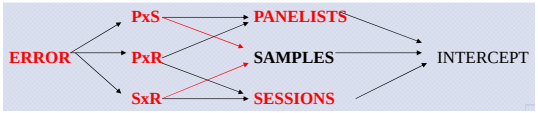
Analysis of the typical sensory data set

Problems of this test:

- Does not take the "error" due to the interactions properly into account
- A small average sample difference may be called significant even though there is a large,say, panelist x sample OR session x sample interaction
- The result of this test cannot be generalized to panels in general nor SESSIONS in general.
- Solution: use RANDOM effects (Mixed Model) on **BOTH!!**

Analysis of the typical sensory data set

- **3-way ANOVA for each variable**
- **Panelists AND Sessions as random effects**



Main issue: Test for sample differences:

$$F = \frac{MS_{\text{Sample}}}{MS_{\text{Panelist x Sample}} + MS_{\text{Session x Sample}} - MS_{\text{Error}}}$$

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Bonferroni correction

Comparing all combinations of 6 products: 6x5/2=15 comparisons

The (family wise) type I error: >>5%
(In cases with no difference, there is a large chance that at least one out of 15 tests become siginificant

Solution: In each of the 15 pairwise test, use 5%/15=0.33% in each test. Or:

$$LSD = t_{0.9967}(45)\sqrt{2MS_{Assessor*\text{Pr}oduct}/30}$$

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$$LSD = t_{0.9967}(45)\sqrt{2MS_{MixedError}/30}$$

$$MS_{\text{MixedError}} = MS_{\text{Panelist x Sample}} + MS_{\text{Session x Sample}} - MS_{\text{Error}}$$

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