ANOVA
(GLM- Repeated measures)

Jantien Donkers
When to use..

- **T-test**: 2 conditions testing 1 independent variable (e.g. text complexity – simple/complex in relation to number of recalled words)

- **ANOVA**: 3 or more conditions testing 1 (one way ANOVA) or more (two way ANOVA) variables
ANOVA’s

- F-ratio
  - Size of the variance due to the experimental conditions in relation to the error (unexpected) variance
- Degrees of freedom (df)
ANOVA’s (2)

- H0: all means are equal
- Alternative: all of means are different, or just one of them

- Variation among groups is compared to variation within groups: a relatively large difference is evidence against H0
Parametric assumptions

- Experimental scores are measured on an *interval scale*
- Scores are *normally distributed*
- Variability of scores for each conditions should be roughly the same (*homogeneity of variance*)
This experiment

- 6 conditions testing 2 independent variables
- Dependent variable: reading time
This experiment (2)

- a self-paced reading study in Dutch
- “who” and “which” questions
- specificity and structure
Why?

- In various research it is observed that "which" questions are more difficult than "who" questions, but:
- It has never been addressed why this is the case
Variable 1: specificity

“Who”  
Wie heeft de keizer gezocht in de kelder?

“Which” generic  
Welke persoon heeft de keizer gezocht in de kelder?

“Which” specific  
Welke bediende heeft de keizer gezocht in de kelder?
Variable 2: structure

- Sentence structure is manipulated by context:

**SO**
Terwijl de dronken bediende een dutje deed, zocht de nuchtere bediende de keizer in de kelder.

**OS**
Terwijl de dronken bediende een dutje deed zocht de keizer de nuchtere bediende in de kelder.
Overview conditions

- 3x2 design: 6 conditions

<table>
<thead>
<tr>
<th>Variable</th>
<th>SO</th>
<th>OS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Who</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WhichGen</td>
<td></td>
<td></td>
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<tr>
<td>WhichSpec</td>
<td></td>
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</tr>
</tbody>
</table>

- 8 scenario/question combinations per conditions (total of 48)
Participants

- 48 (14 male, 34 female)
- Mean age 22.1 (sd 2.34)
- Normal or corrected to normal vision
- Paid for participation
Procedure & analysis

- Phrase-by-phrase self-paced reading (using E-prime software package)
- "Moving window"

- Accuracy: participants had to judge a provided answer (correct/incorrect) by pressing the corresponding button

- Reading times and accuracy analyzed
Terwijl de dronken bediende een hapje at, zocht de nuchtere bediende de keizer in de kelder.
Wie
heeft
gezocht
in de kelder?
de nuchtere bediende
Hypotheses

- Set-restriction ("specificity") is a (the?) complicating factor during wh-question processing
  - Also when the questions are presented within an appropriate context
- BUT
  - Processing difficulties in set-restricted wh-questions interact with difficulties in sentence structure
Hypothesis 1

- Set-restriction is a complicating factor during wh-question processing
  - WhichSpec > WhichGen = Who

Alternatives:
  - WhichSpec = WhichGen > Who
  - WhichSpec = WhichGen = Who

(in reading times (RTs))
Hypothesis 2

- Processing difficulties in set-restricted wh-questions interact with difficulties in sentence structure
  - \( \text{WhichSpec OS} > \text{WhichGen OS} = \text{Who OS} \)
  - \( \text{WhichSpec SO} = \text{WhichGen SO} = \text{Who SO} \)

Possible alternative:
- All wh-types \( \text{OS} > \text{SO} \)
Segment of interest

- “Point of integration”:

Welke bediende heeft de keizer gezocht in de kelder?

- At this position (i.e. participle) it becomes clear which role each individual NP (Wh-phrase and “de keizer”) plays
Repeated measures/ SPSS
Data

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<th>subject</th>
<th>span</th>
<th>cond</th>
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</table>
Data pre-processing (1)

- Define conditions (in terms of factors)
  - Cond 1 or 2: Qtype 1 (Who)
  - Cond 1 or 4 or 5: Order 1 (SO)
- Define item groups
- Define lists
Data pre-processing (2)

- Define cut-offs (outliers)
- Calculate segment means and sds
  - Per subject
  - Per item
- Define limits (mean + 2sd)
- Replace outliers and >limits by mean + 2sd
- Data-transformation (suitable for SPSS)
Data pre-processing (3)

- Write syntax script

```
GET FILE = 'D:\experiments\experiment1\analysis\data.sav'.

IF (cond=1 OR cond=2) Qtype=1.
IF (cond=3 OR cond=4) Qtype=2.
IF (cond=5 OR cond=6) Qtype=3.
IF (cond=1 OR cond=4 OR cond=5) Order=1.
IF (cond=2 OR cond=3 OR cond=6) Order=2.

IF ANY(item, 2,4,6,16,18,22,28,31) itemgr=1.
IF ANY(item, 10,14,17,27,32,35,40,48) itemgr=2.
IF ANY(item, 3,8,20,21,26,33,37,47) itemgr=3.
```
Data pre-processing (4)

- Write syntax script

```
COMPUTE phr1rt1=phr1rt.
IF(phr1rt<150 OR phr1rt>5000) phr1rt1=0.
MISSING VALUES phr1rt1(0).

COMPUTE phr2rt1=phr2rt.
IF(phr2rt<150 OR phr2rt>5000) phr2rt1=0.
MISSING VALUES phr2rt1(0).

COMPUTE phr3rt1=phr3rt.
IF(phr3rt<140 OR phr3rt>5000) phr3rt1=0.
MISSING VALUES phr3rt1(0).

COMPUTE phr4rt1=phr4rt.
```
Data pre-processing (5)

- Write syntax script

```plaintext
COMPUTE xphr1rt = phr1rt1.
IF (phr1rt1 < lopp1) xphr1rt = lopp1.
IF (phr1rt1 > hipp1) xphr1rt = hipp1.
IF (phr1rt1 < loit1) xphr1rt = loit1.
IF (phr1rt1 > hiit1) xphr1rt = hiit1.
COMPUTE hmean=(hipp1+hiit1)/2.
COMPUTE lmean=(lopp1+loit1)/2.
IF (((phr1rt1 > hipp1) AND (phr1rt1 > hiit1)) xphr1rt=hmean.
IF (((phr1rt1 < lopp1) AND (phr1rt1 < loit1)) xphr1rt=lmean.

COMPUTE xphr2rt = phr2rt1.
IF (phr2rt1 < lopp2) xphr2rt = lopp2.
IF (phr2rt1 > hipp2) xphr2rt = hipp2.
```
GLM – Repeated measures

- SPSS data file with subject means
- SPSS data file with item means
GLM – Repeated measures
GLM – Repeated measures

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GLM – Repeated measures
GLM – Repeated measures

GLM
    p1bs p1bo p1gs p1go p1ss p1so BY listx
    /WSFACTOR = qtype 3 Polynomial order 2 Polynomial
    /METHOD = SSTYPE(3)
    /CRITERIA = ALPHA(.05)
    /WSDESIGN = qtype order qtype*order
    /DESIGN = listx.
GLM – Repeated measures
Effects (subject analysis)

- Main effect of question type (who, whichGen, whichSpec)
- Main effect of order (SO, OS)
- Interaction question type by order
- Interaction …by list
Effect or interaction?

- Plot your data!
  - Mistake in labelling
  - Effect can be counter-intuitive
  - Post-hoc analyses
Accuracy

Accuracy

SO  OS  SO  OS  SO  OS
Who WhichGen WhichSpec
Accuracy

- The data suggest that answers following OS structures are more difficult to judge that those following SO questions.
Reading times

Mean reading times per segment

Segment: Wh, aux, NP2, participle, PP

Reading times:
- Who SO
- Who OS
- WhichGen SO
- WhichGen OS
- WhichSpec SO
- WhichSpec OS
Reading times (2)

- **Phrase 1:** wh-element

```
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<td>WhichSpec</td>
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</tbody>
</table>
```

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Reading times (3)

- Phrase 2: auxiliary

### Phrase 2

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Reading times (4)

- Phrase 3: NP2

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Reading times (5)

- Phrase 4: Participle

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What do I want to know?

- So the separate question types behave differently?
- Is this connected to word order complexity?
Reading times (5)

- Phrase 4: Participle

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Reading times (5)

- Phrase 4: Participle
Reading times (5)

- Phrase 4: Participle

![Diagram of reading times for different phrases and structures]

- SO OS SO OS OS

- Reading times (5):
  - SO OS SO OS OS
  - Who
  - WhichGen
  - WhichSpec

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What do I want to know?

- So the separate question types behave differently?
  - Who and WhichGen seem to pattern alike, compared to WhichSpec
Reading times SO

Mean reading times per segment

- Who SO
- WhichGen SO
- WhichSpec SO

Segment:
- Wh
- aux
- NP2
- participle
- PP

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Reading times OS

Mean reading times per segment

Reading time

Segment

Wh aux NP2 participle PP

Who OS WhichGen OS WhichSpec OS

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What do I want to know?

- Is a different pattern for the WhichSpec condition only connected to word order complexity?

- The increased reading times for WhichSpec are confined to the OS structure-conditions. In SO conditions the average reading times were comparable.
Reading times (6)

- Phrase 5: PP

![Bar chart showing reading times for different constructions: Who, WhichGen, WhichSpec. The x-axis represents the sentence order (SO, OS) and the y-axis represents the reading times in milliseconds.]