



**University of
Zurich^{UZH}**

Department of Computational Linguistics

ECL II

Experimental methods & psycholinguistic phenomena

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Spring 2024



Lab tour

Lab tour in the Digital Linguistics Lab (DiLi lab) in the basement of AND on March 31, 2023 at 12:15-13:45.

Tour guide: ***tba***

Date and time: ***tba***



Schedule for today

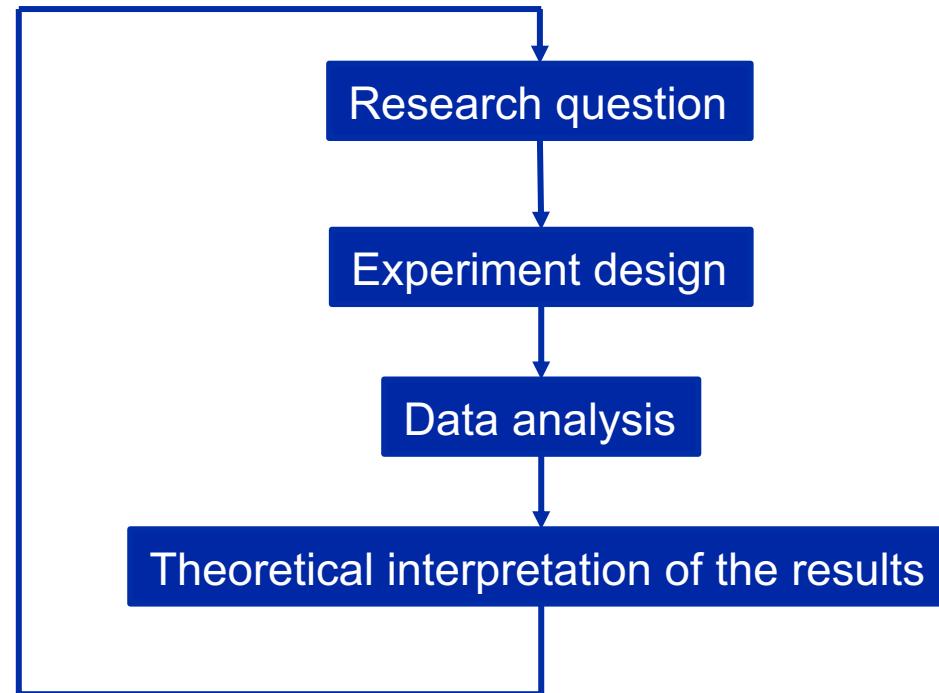
- Last week, we got to know a couple of phenomena observed during human sentence processing that a good model of human sentence processing must be able to account for
- Today, we will ...
 - look at how to reveal/measure these phenomena
 - Experiment design
 - Experimental methods
 - see some examples of the use of these designs/methods
 - get to know a wider range of psycholinguistic phenomena



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Experimental methods





Designing an experiment: Terminology

- Observation versus experiment
 - Exploratory data analysis versus hypothesis testing
- Hypothesis
 - Idea that is being tested with the experiment
- Operational definition
 - Link between the (vague) concepts in the research idea and what is measured in the experiment
- Experimental manipulation
 - The variable you manipulate or vary in an experimental study to explore its effects



Independent variable

- Can be continuous (i.e., real valued), ordinal, or a factor with categorical levels
- Experimental condition: combination of levels of the different factors
- Within-subject variable versus between-subject variable
- Within-item variable versus between-item variable
- Item: a pair/triplet/... of the same stimulus in different experimental conditions (only applicable for within-item manipulations)
- Experimental variable versus quasi-experimental variable
- Fully crossed factorial design: each level of each factor is combined with each level of all other factors.



Fully crossed factorial design: Example

Method: Lexical decision task

Factor I: Word length {short, long}

Factor II: Phonotactic regularity {regular, irregular}

		Factor I	
		short, regular	long, regular
Factor II	short, regular	short, regular	long, regular
	short, irregular	short, irregular	long, irregular



Latin Square design

- Used in experiments with within-subject, within-items manipulations
- Avoids that participants see the same item multiple times (i.e., in each of the experimental conditions)
- **Items are distributed across different lists** such that on each list each item appears in exactly one condition.
 - The number of lists corresponds to the number of conditions
- Each participant sees only one of the lists.
 - Each participant sees each item exactly once
 - Each participant sees all experimental conditions the same number of times.



Latin Square design: Example for a 2x2x2 fully-crossed design

Factor I: Dependency type: {agreement, reflexive}

Factor II: Grammaticality: {grammatical, ungrammatical}

Factor III: Interference: {interference, no interference}

- All factors are manipulated **within-subjects** and **within-items**.
- $2 \times 2 \times 2 = 8$ experimental conditions
- We need to create a number of items that is a multiple of the number of experimental conditions (e.g. 48)
 - Each item consists of 8 versions of a sentence, i.e., one version for each experimental condition
- Let's look at an example



Factor I: Dependency type: {agreement, reflexive}

Factor II: Grammaticality: {grammatical, ungrammatical}

Factor III: Interference: {interference, no interference}

Relabeling all possible combinations of factor levels as conditions:

- a. agreement, grammatical, interference
- b. agreement, grammatical, no interference
- c. agreement, ungrammatical, no interference
- d. agreement, ungrammatical, interference
- e. reflexives, grammatical, interference
- f. reflexives, grammatical, no interference
- g. reflexives, ungrammatical, no interference
- h. reflexives, ungrammatical, interference

a. *Agreement; grammatical; interference*

The amateur bodybuilder^{+singular}_{+local subject} who worked with the personal trainer^{+singular}_{-local subject} amazingly was^{singular}_{local subject}} competitive for the gold medal.

b. *Agreement; grammatical; no interference*

The amateur bodybuilder^{+singular}_{+local subject} who worked with the personal trainers^{-singular}_{-local subject} amazingly was^{singular}_{local subject}} competitive for the gold medal.

c. *Agreement; ungrammatical; no interference*

*The amateur bodybuilder^{-plural}_{+local subject} who worked with the personal trainer^{-plural}_{-local subject} amazingly were^{plural}_{local subject}} competitive for the gold medal.

d. *Agreement; ungrammatical; interference*

*The amateur bodybuilder^{-plural}_{+local subject} who worked with the personal trainers^{+plural}_{-local subject} amazingly were^{plural}_{local subject}} competitive for the gold medal.

e. *Reflexive; grammatical; interference*

The amateur bodybuilder^{+singular}_{+c-com} who worked with the personal trainer^{+singular}_{-c-com} amazingly injured himself^{singular}_{c-com}} on the lightest weights.

f. *Reflexive; grammatical; no interference*

The amateur bodybuilder^{+singular}_{+c-com} who worked with the personal trainers^{-singular}_{-c-com} amazingly injured himself^{singular}_{c-com}} on the lightest weights.

g. *Reflexive; ungrammatical; no interference*

*The amateur bodybuilder^{-plural}_{+c-com} who worked with the personal trainer^{-plural}_{-c-com} amazingly injured themselves^{plural}_{c-com}} on the lightest weights.

h. *Reflexive; ungrammatical; interference*

*The amateur bodybuilder^{-plural}_{+c-com} who worked with the personal trainers^{+plural}_{-c-com} amazingly injured themselves^{plural}_{c-com}} on the lightest weights.

Jäger et al. 2020



Latin Square design: Example with 8 experimental conditions

List 1	List 2	List 3	List 4	List 5	List 6	List 7	List 8
Item 1a	Item 1b	Item 1c	Item 1d	Item 1e	Item 1f	Item 1g	Item 1h
Item 2b	Item 2c	Item 2d	Item 2e	Item 2f	Item 2g	Item 2h	Item 2a
Item 3c	Item 3d	Item 3e	Item 3f	Item 3g	Item 3h	Item 3a	Item 3b
Item 4d	Item 4e	Item 4f	Item 4g	Item 4h	Item 4a	Item 4b	Item 4c
Item 5e	Item 5f	Item 5g	Item 5h	Item 5a	Item 5b	Item 5c	Item 5d
Item 6f	Item 6g	Item 6h	Item 6a	Item 6b	Item 6c	Item 6d	Item 6e
Item 7g	Item 7h	Item 7a	Item 7b	Item 7c	Item 7d	Item 7e	Item 7f
Item 8h	Item 8a	Item 8b	Item 8c	Item 8d	Item 8e	Item 8f	Item 8g
Item 9a	Item 9b	Item 9c	Item 9d	Item 9e	Item 9f	Item 9g	Item 9h
...
Item 48h	Item 48a	Item 48b	Item 48c	Item 48d	Item 48e	Item 48f	Item 48g



Dependent variable

- Variable that is measured in the experiment
- The experimenter wants to investigate the effect of the independent variable(s) on the dependent variable
- Typical dependent variables in linguistic experiments are: reaction time, fixation duration, response accuracy, etc.
- The dependent variable can be continuous (i.e., real valued), ordinal, or a factor with categorical levels
- Often, a method provides multiple dependent variables (e.g., different reading measures in eye tracking experiments)
- Critical region/region of interest: Word(s) (or morphemes, etc.) on which the measurement is performed



Spill over and wrap-up effects

Spill over effects

- increased reading times on the stimulus region immediately following the site of an immediate effect
- reflects later phases of comprehension and can be indicators of processing difficulty that is either persistent or delayed

Wrap-up effects

- Tendency for humans to spend more time on the last word of a sentence or clause, due to ...
 - actions such as “the constructions of inter-clause relations.” (Just and Carpenter, 1980)
 - attempts to resolve previously postponed comprehension problems, which could have been deferred in the hope that upcoming words would resolve the problem. (Rayner et al. 2000)
 - hesitation when crossing clause boundaries is out of efficiency; readers do not want to have to return to the clause later, so they take the extra time to make sure there are no inconsistencies in the prior text.(Hirotani et al. 2006)



Validity of an experiment or a measurement

Internal validity:

- Is the experiment measuring what it is intended to measure?
- Closely related to the operational definition: Is the experimental procedure an adequate definition of the (usually very abstract) construct that we want to measure?

External validity:

- Generalizability: can the results from an (internally valid) experiment be applied to other situations (e.g., outside the lab) and other populations (e.g., other languages; speakers with a different socio-linguistic background ...)?



Reliability of an experiment or a measurement

- Is the measurement consistent?
→ When measuring the same thing multiple times, does the measurement record the same value?



Confound

- A confound, or confounding variable, is a **systematic**, but unplanned variable that provides an alternative explanation for the results of the experiment.



Observation versus experiment

- Implications for causality
- In many research scenarios, only observational data is available
 - Linguistic corpora are observational data
- Most linguistic experiments do not manipulate experimental variables, but merely quasi-experimental variables.
- Exploratory data analysis versus hypothesis testing



Example: From a research question to an experiment design

Research question:

Is language processing difficulty mainly determined by working memory load or by predictability of the input?

Are subject or object relative clauses in Chinese easier to process?

Is there any difference depending on modification type?

Designing an experiment...

Jäger et al. (2015)



Example: From a research question to an experiment design

- Method: **Self-paced reading**
- Independent variables: 2 factors:
 - Factor I with 2 levels manipulated within-subjects and within-items:
Relative clause type: {subject relative clause, object relative clause}
 - Factor II with 2 levels manipulated within-subjects and within-items:
Modification type: {object modifying relative clause, subject modifying relative clause}



2x2 fully crossed within-subjects, within-items factorial design

→ Arrange items according to a Latin Square

- Dependent variable: Reading time at the verb and noun inside the relative clause



Example: From a research question to an experiment design

a. Subject-modifying SR

[_{RC}	t_i	邀请	男孩	的]	女孩	认识	老师。
		yaoqing	nanhai	de		nühai _i	renshi	laoshi.

'The girl who invites the boy knows the teacher.'

b. Subject-modifying OR

[_{RC}	男孩	邀请	的]	女孩	认识	老师。
	nanhai	yaoqing	t_i	de	nühai _i	renshi	laoshi.

'The girl who the boy invites knows the teacher.'

c. Object-modifying SR

老师	认识	邀请	男孩	的	女孩。
laoshi	renshi	[_{RC}	t_i	yaoqing	nanhai.

teacher know

invite

boy	的]	女孩。
REL			nühai _i .

girl

'The teacher knows the girl who invites the boy.'

d. Object-modifying OR

老师	认识	男孩	邀请	的	女孩。
laoshi	renshi	[_{RC}	nanhai	yaoqing	t_i

teacher know

boy

invite	de]	女孩。
	REL		nühai _i .

girl

'The teacher knows the girl who the boy invites.'



Methods used for linguistic experiments

- Self-paced reading
- Eye tracking while reading
- Visual world eye tracking
- Lexical decision tasks
- Priming (+lexical decision or another secondary task)
- Sentence completion
- Ratings (acceptability, plausibility, grammaticality, etc.)
- Comprehension questions
- Event-related potentials (ERP)
- Various brain imaging methods (e.g., fMRI)
- ...



Typical dependent variables in linguistic experiments

- Reaction time
 - Reading time
 - Fixation duration, saccade type (regression vs. fixation) and other measures derived from eye movements
 - Response accuracy
- Most dependent variables are either continuous or binary



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Psycholinguistic phenomena



Psycholinguistic phenomena

- See some examples of experimental designs and methods we just saw
- Get to know some psycholinguistic phenomena
 - Frequency effects
 - Locality effects
 - Anti-locality effects
 - Similarity-based interference
 - Local coherence
 - Grammatical illusions



Frequency effects

The frequency of a word (i.e., lexical frequency) or a syntactic structure affects the ease with which this word or constituent is being processed.

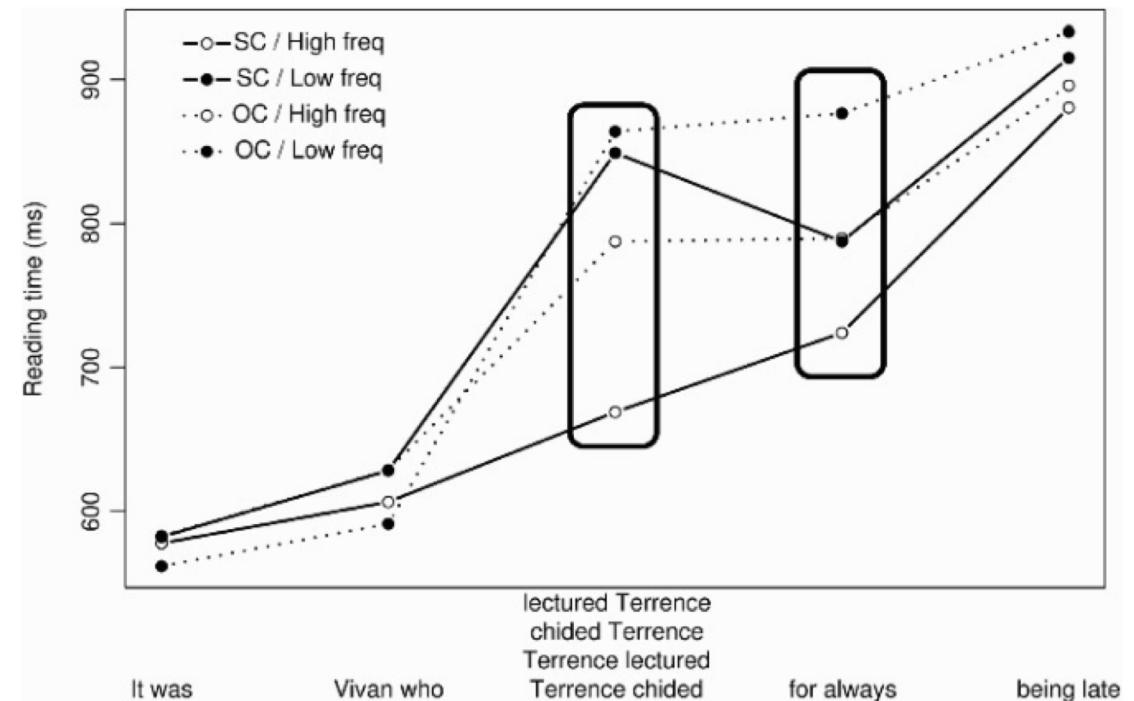
- **Self-paced reading experiment** (Tily et al. 2010)
 - Manipulation: frequency of the verb in unambiguous subject/object extracted clefts
 - a. *High frequency/subject extracted*
It was Vivian who lectured Terrence for always being late.
 - b. *High frequency/object extracted:*
It was Vivian who Terrence lectured for always being late.
 - c. *Low frequency/subject extracted:*
It was Vivian who chided Terrence for always being late.
 - d. *Low frequency/object extracted:*
It was Vivian who Terrence chided for always being late.

Tily et al. 2010

Frequency effects

- **Self-paced reading experiment** (Tily et al. 2010)
 - Manipulation: frequency of the verb in unambiguous subject/object extracted clefts

→ Reading time higher for low-frequency verbs





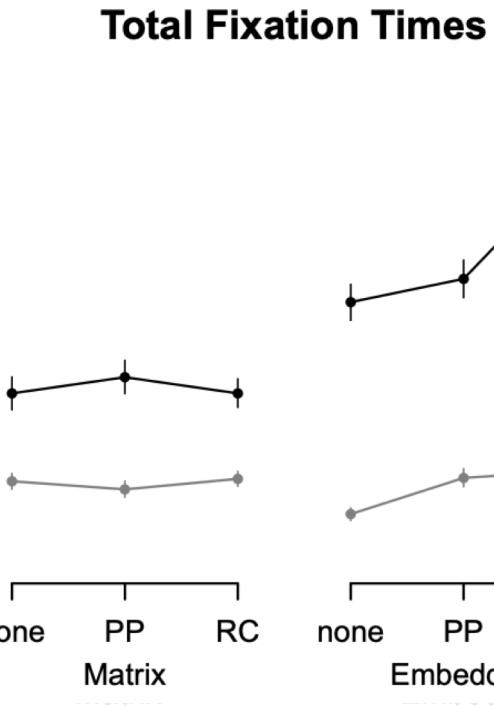
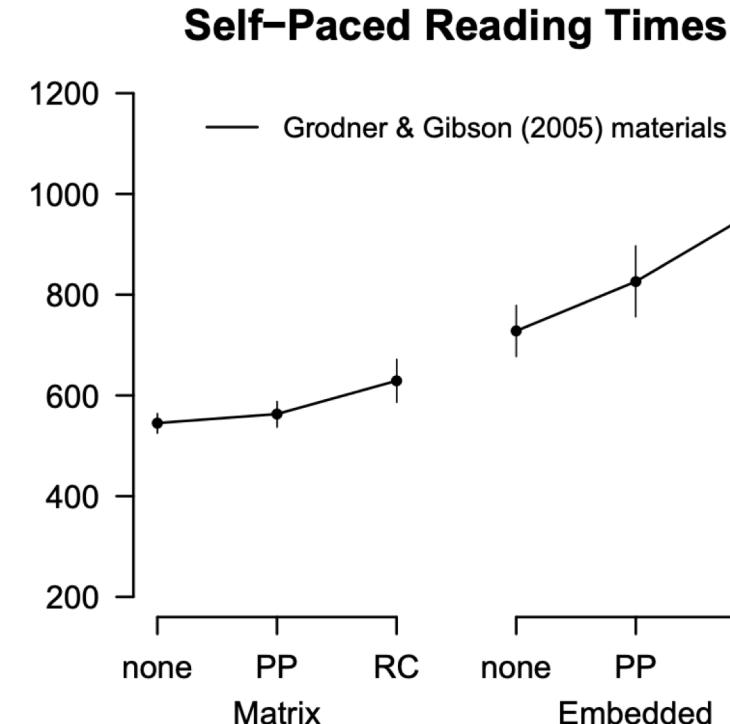
Locality effects

More dependents preceding a governing verb increases processing difficulty at the verb

- **Testing Locality Effects Using SPR and eye-tracking** (Gibson et al. 2011)
- 30 sentences in 6 different conditions

CONDITION	EXAMPLE
<i>Unmodified</i>	The child <u>played</u> the sports that were hard to master.
<i>PP-modified</i>	The child from the school <u>played</u> the sports that were hard to master.
<i>Matrix</i>	
<i>RC-modified</i>	The child who was from the school <u>played</u> the sports that were hard to master.
<i>Unmodified</i>	The sports that the child <u>played</u> were hard to master.
<i>PP-modified</i>	The sports that the child from the school <u>played</u> were hard to master.
<i>Embedded</i>	
<i>RC-modified</i>	The sports that the child who was from the school <u>played</u> were hard to master.

Locality effects



- Significant locality effect in both the matrix and embedded verb conditions for SPR
- Confirmed by **some** measures of ET

Anti-locality effects

More preceding dependents facilitates processing at the verb

- Eye-tracking study by Levy & Keller (2013)
- RQ: What are the effects of adding preverbal dependents varying *in predictive value* to a verb-final clause?

...daß der Freund DEM Kunden das Auto verkaufte
...that the friend the client the car sold
'...that the friend sold the client a car...'

...daß der Freund DES Kunden das Auto verkaufte
...that the friend the client the car sold
'...that the friend of the client sold a car...'



Anti-locality effects

- Manipulations
 - position of the dative NP (subordinate or relative clause)
 - position of a PP modifier (subordinate or relative clause)

→ Hypothesis: Additional material in the relative clause should make the processing of the head verb more difficult



ADJ subordinate
DAT subordinate

- (4) a. Nachdem der Lehrer zur zusätzlichen Ahndung des mehrfachen Fehlverhaltens **dem ungezogenen Sohn des fleißigen Hausmeisters** den Strafunterricht verhängte, hat Hans Gerstner den Fußball versteckt, und damit die Sache bereinigt.
After the teacher as additional payback for multiple wrongdoings **the.DAT son the.GEN industrious janitor** the.ACC detention.classes imposed, has Hans Gerstner the.ACC football hidden, and thus the affair corrected.
"After the teacher imposed detention classes on the naughty son of the industrious janitor as additional payback for the multiple wrongdoings, Hans Gerstner hid the football, and thus corrected the affair."

ADJ main
DAT subordinate

- b. Nachdem der Lehrer **dem ungezogenen Sohn des fleißigen Hausmeisters** den Strafunterricht verhängte, hat Hans Gerstner zur zusätzlichen Ahndung des mehrfachen Fehlverhaltens den Fußball versteckt, und damit die Sache bereinigt.
After the teacher **the.DAT naughty son the.GEN industrious janitor** the.ACC detention.classes imposed, has Hans Gerstner as additional payback for multiple wrongdoings the.ACC football hidden, and thus the affair corrected.
"After the teacher imposed detention classes on the naughty son of the industrious janitor, Hans Gerstner hid the football as additional payback for the multiple wrongdoings, and thus corrected the affair."

ADJ subordinate
DAT main

- c. Nachdem der Lehrer zur zusätzlichen Ahndung des mehrfachen Fehlverhaltens den Strafunterricht verhängte, hat Hans Gerstner **dem ungezogenen Sohn des fleißigen Hausmeisters** den Fußball versteckt, und damit die Sache bereinigt.
After the teacher as additional payback for multiple wrongdoings **the.DAT naughty son the.GEN industrious janitor** the.ACC football hidden, and thus the affair corrected.
"After the teacher imposed detention classes as additional payback for the multiple wrongdoings, Hans Gerstner hid the football from the naughty son of the industrious janitor, and thus corrected the affair."

ADJ main
DAT main

- d. Nachdem der Lehrer den Strafunterricht verhängte, hat Hans Gerstner zur zusätzlichen Ahndung des mehrfachen Fehlverhaltens **dem ungezogenen Sohn des fleißigen Hausmeisters** den Fußball versteckt, und damit die Sache bereinigt.
After the teacher the.ACC detention.classes imposed, has Hans Gerstner as additional payback for multiple wrongdoings **the.DAT naughty son the.GEN industrious janitor** the.ACC football hidden, and thus the affair corrected.
"After the teacher imposed detention classes, Hans Gerstner hid the football from the naughty son of the industrious janitor as additional payback for the multiple wrongdoings, and thus corrected the affair."

italics: PP adjunct
bold: dative NP

critical region



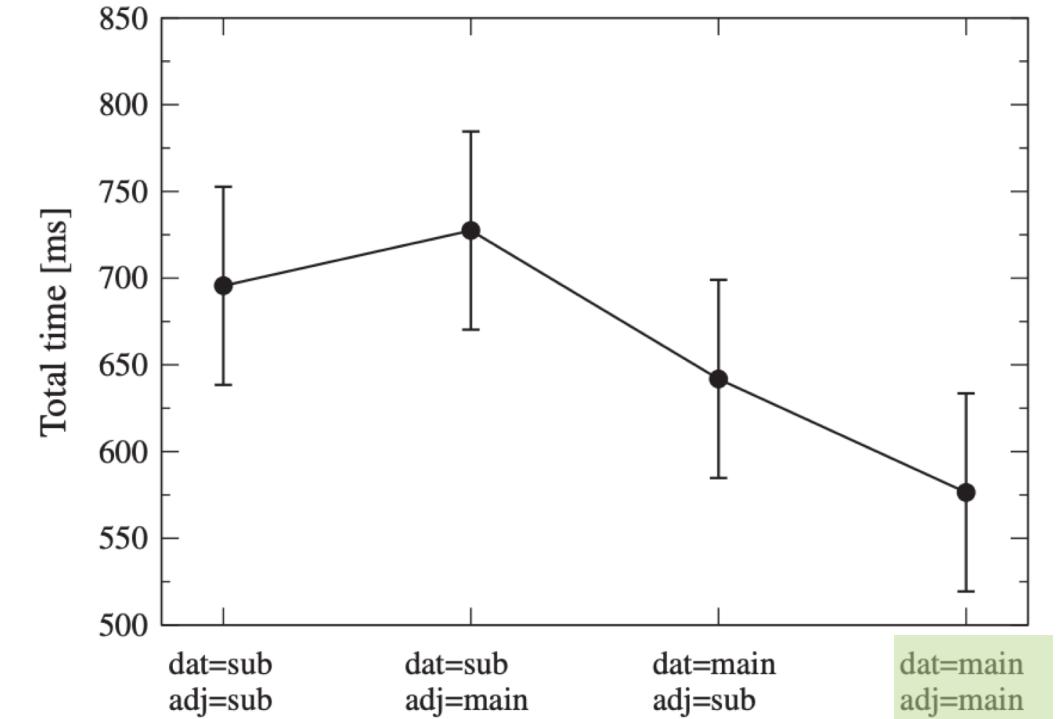
Anti-locality effects

- Advantages of the design
 - Stimuli induce high memory load, which has previously been expected to result only in locality effects
 - Eliminating confounds: all sentences are of equal length in all conditions, the same words precede the critical region, and the critical region and its immediately preceding words are the same across all conditions

Anti-locality effects

Results

- The presence of a dative NP in the main clause leads to a **decrease** in reading time at the main clause's final participial verb
 - Although subject more displaced from matrix verb!
 - The dative NP generates expectations about the participle to follow, which is then easier to process
- Encountering a preverbal dative constrains the argument structure



d. Nachdem der Lehrer den Strafunterricht verhängte, hat Hans Gerstner zur zusätzlichen Ahndung des mehrfachen Fehlverhaltens dem ungezogenen Sohn des fleißigen Hausmeisters den Fußball versteckt, und damit die Sache bereinigt.
After the teacher imposed detention classes imposed, has Hans Gerstner as additional payback for multiple wrongdoings the.DAT naughty son the.GEN industrious janitor the.ACC football hidden, and thus the affair corrected.
“After the teacher imposed detention classes, Hans Gerstner hid the football from the naughty son of the industrious janitor as additional payback for the multiple wrongdoings, and thus corrected the affair.”



Similarity-based interference

Observed when a grammatically inaccessible element matches in features with the grammatically accessible antecedent in a linguistic dependency

- Similarity-based interference is observed when a grammatically inaccessible element matches in features with the grammatically accessible antecedent in a linguistic dependency
 1. The banker that the lawyer admired ____ climbed the mountain.
 2. The banker that you/Joe admired ____ climbed the mountain.
- In both clauses, the relative clause subject intervenes between the head of the relative and the object gap. In (a) the head and the subject match in the NP type (both are full NPs) whereas in (b) the head is of a different NP type as the subject
- For relative clauses where head and subject match (a) there is more interference compared to when features do not match (b)



Similarity-based inference

- Eye-tracking study (Gordon et al. 2006)
 - Stimuli: subject-extracted and object-extracted relative clauses with the NP in the RC either as a description (the barber) or a name.
 1. The banker that praised the barber/Sophie climbed the mountain just outside of town.
 2. The banker that the barber/Sophie praised climbed the mountain just outside of town.
 - Additional comprehension questions after each sentence to check if they got the right understanding of the relationship of the critical NPs and the verbs



Similarity-based interference

- “There was a main effect of NP type on comprehension question accuracy such that questions related to sentences with embedded names were answered more accurately (proportion correct = .94) than questions related to sentences with embedded descriptions (proportion correct = .87); $F1(1,35) = 17.86$, MSE = .06, $p < .001$, $F2(1,23) = 5.89$, MSE = .18, $p < .02$ ”
→ Accuracy is higher if the second NP is a name and not descriptive
- “There was a main effect of NP type on gaze duration on the RC region, such that longer gaze durations (664 msec) were observed for sentences with embedded descriptions than for sentences with embedded names (530 msec; $F1(1,35) = 38.06$, MSE = 74084, $p < .001$, $F2(1,23) = 21.68$, MSE = 121554, $p < .001$)”
→ Measured reading time is longer when both NPs are of the same type



Local coherence

Under certain circumstances, the human sentence processing system creates local syntactic structures that are not compatible with the previous input

- Sentence processing complexity is not only influenced by the globally coherent structure from the beginning to its current point of processing of a sentence but also by locally coherent sub-parses
 - (a) The coach chided the player tossed a frisbee by the opposing team.
 - (b) The coach chided the player who was tossed a frisbee by the opposing team.
 - *Tossed* in (a) could either be past participle or a past tense main verb. Therefore (a) contains a main clause as a local subsequence (the player tossed a frisbee) where *tossed* is a past-tense
 - This subsequence is embedded in a context that would exclude the main verb analysis.
 - If the human sentence processor did only global analyses it should never consider *tossed* as the main verb given the previous context
- Reading times of (a) should be the same as of b



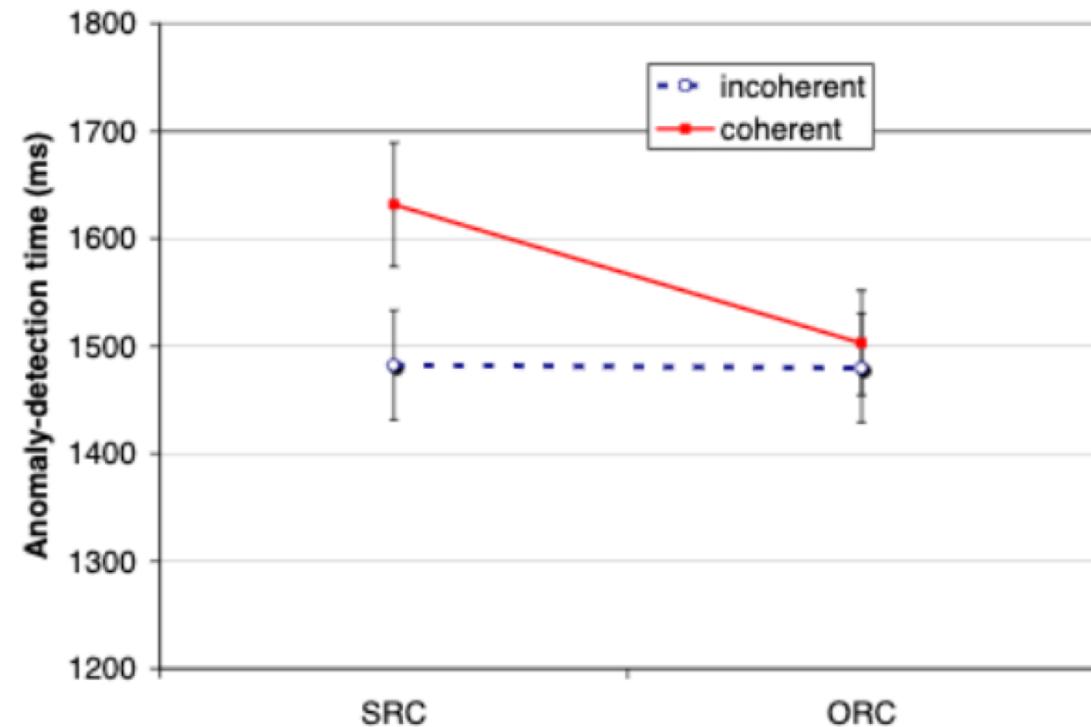
Local coherence

- Reaction-experiment: 4 German sentences with center-embedded subject relative clauses (SRC) and object relative clauses (ORC) and inserted errors. The errors are inserted NPs
- In SRCs a local coherent subsequence would be nominative and in ORCs accusative
 - SRC, incoherent: Der Abgeordnete, der *den Journalisten beschimpft* *[*den Politiker*], liefert die Beweise.
 - SRC, coherent: Der Abgeordnete, der *den Journalisten beschimpft* *[*der Politiker*], liefert die Beweise.
 - ORC, incoherent: Der Abgeordnete, *den der Journalist beschimpft* *[*der Politiker*], lieferte die Beweise.
 - ORC, coherent: Der Abgeordnete, *den der Journalist beschimpft* *[*den Politiker*], liefert die Beweise.

→ Participants were presented 24 sentences of each type in word-by-word rapid serial visual presentation and had to press a button as soon as they noticed a mistake (*anomaly detection time*)

Local coherence

- In overall accuracy, no difference between the conditions
- Anomaly detection time was longer for errors that were locally coherent compared to errors that were locally incoherent (for SRCs)





Grammatical illusions

Phenomenon where the human parser deems a structure grammatical, despite its being ungrammatical

Example

1. *The apartment that the maid who the service had sent over was cleaning every week was well decorated*
2. **The apartment that the maid who the service had sent over was well decorated.*

Ungrammatical sentences containing center embedding, such as (1b), were rated significantly better than grammatical sentences, such as (1a) (Engelmann and Vasishth 2009).

- For some grammatical constraints, different instantiations are more/less prone to illusions → selective failibility



Grammatical illusions

Verb agreement in English: the morphological features of the finite verb or auxiliary must agree with the corresponding features on the subject NP. However, subject-verb agreement is prone to grammatical illusion:

(2) *The key to the cabinets are on the table.*

→ The auxiliary erroneously agrees with the embedded plural noun (*cabinets*) instead of the singular subject (*key*). Agreement attraction errors like this occur frequently in naturalistic speech and writing, and they also tend to be overlooked in comprehension studies.

Attraction effects are selective: in English, they are only caused by plural nouns (*cabinets* in (2)) but never by singular nouns. Moreover, attraction effects lead to illusions of grammaticality (3a), but never to illusions of ungrammaticality (3b).

(3a) *The key to the cabinets unsurprisingly were on the table.*

(3b) *The key to the cabinets unsurprisingly was on the table*

(Phillips et al. 2007)



Grammatical illusions

Embedded clauses in German where the case-marking on the subject NP is incompatible with the clause-final verb

(4a) *... *dass der Mutter_[DAT] das Buch geschickt hat* 90% rejection

“... that the mother sent the book”

(4b) *... *dass die Mutter_[NOM] das Buch geschickt wurde* 60% rejection

“... that the mother was sent the book”

Speakers reliably reject sentences like (4a), in which the dative-marked subject is followed by an active verb that does not license dative case on its subject, but they show a high rate of acceptance for the equally ungrammatical (4b), in which a nominative-marked subject is followed by a passive verb that requires a dative subject.

→ unmarked subjects induce a much higher rate of grammatical illusion (Phillips et al. 2011).



Summary

- Using an experiment, we can test a specific hypothesis in a setting where we manipulate one or several conditions (=independent variables) on a specific outcome (=dependent variable).
- In a Latin Square design, we distribute items across a number of lists that corresponds to the number of conditions such that each participant sees each item exactly once and each participant sees all experimental conditions the same number of times.
- When designing an experiment, we need to be conscious of its internal and external validity as well as rule out (or at least be aware of) possible confounds.
- Important psycholinguistic phenomena include frequency effects, locality and anti-locality effects, similarity-based interference, local coherence and grammatical illusions.



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Questions?



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