Readers with less cognitive control are more affected by surprising content: Evidence from a self-paced reading experiment in German

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Aim:

- investigate how the processing of expected and unexpected upcoming words is affected by
  - cognitive control
  - working memory capacity
  - reading skills
How to disentangle the easier integration into the context and predictions?


a. The day was breezy so the boy went outside to fly a kite.
b. The day was breezy so the boy went outside to fly an airplane.
How to disentangle the easier integration into the context and predictions?

A strong prediction for a noun phrase will trigger expectations of certain features in its previous determiner or adjective:

   a. The day was breezy so the boy went outside to fly a kite. PREDICTABLE DETERMINER
   b. The day was breezy so the boy went outside to fly an airplane. UNPREDICTABLE/SURPRISING DETERMINER
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Working memory capacity (WMC)

Does the ability to temporarily store and manipulate information (WMC) affect the ability to predict upcoming words?
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We can measure WMC using the operation span task (Turner & Engle, 1989)
Working memory capacity (WMC)

Does the ability to temporarily store and manipulate information (WMC) affect the ability to predict upcoming words?

We can measure WMC using the operation span task (Turner & Engle, 1989)

but note the findings of Otten and Van Berkum (2009)
Reading skills

Does the “prediction ability” depends on the sensitivity to the semantic cues characteristic of skilled readers (Pearlmutter & MacDonald, 1995)?
Reading skills

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We can measure reading skills using the rapid automatized naming task (Denckla & Rudel, 1976)
Reading skills

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![Graph showing RT as a function of reading skills and condition]

- Condition
  - Predictable
  - Unpredictable

- Reading Skills
  - Low
  - Mid
  - High

- RT (Reaction Time)
Cognitive Control

Cognitive control is related to: (Botvinick, Braver, Barch, & Carter, 2001)

- adjustments in perceptual selection
- response biasing
- on-line maintenance of contextual information
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- tasks requiring the subject to override relatively automatic but task-inappropriate responses (Stroop)
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- adjustments in perceptual selection
- response biasing
- on-line maintenance of contextual information
- tasks requiring the subject to override relatively automatic but task-inappropriate responses (Stroop)

Suppression ability

Ability to suppress irrelevant information during comprehension independent of the ability to enhance relevant information (Structure-Building Framework: Gernsbacher, 1997)
Cognitive Control

Cognitive control (≈ Suppression ability) in associative priming (Boudewyn, Long, & Swaab, 2012):

(2) a. In her haste she forgot to buy the apples and oranges. 
ASSOCIATED
b. In her haste she forgot to buy the apples and bread. 
UNASSOCIATED

Results:
▶ stronger N400 effects in words unassociated (bread) to the prime in comparison with associated words (oranges)
▶ participants with less cognitive control showed stronger N400 effects in the unassociated words (bread) in comparison with the associated ones (oranges)
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Cognitive Control

How can we measure cognitive control?

**Stroop task:**
Cognitive Control

How can we measure cognitive control?

Stroop task: BLUE
How can we measure cognitive control?

Stroop task: BLUE - RED
How can we measure cognitive control?

**Stroop task:** BLUE - RED

De Houwer’s (2003) variation of the Stroop task (Stroop, 1935) with also a neutral condition (Brown, 2011)
Cognitive Control: Stroop task

Congruent condition:
Cognitive Control: Stroop task

Congruent condition:

BLUE
Cognitive Control: Stroop task

Neutral condition:
Cognitive Control: Stroop task

Neutral condition:
Cognitive Control: Stroop task

Semantic interference condition:
Cognitive Control: Stroop task

Semantic interference condition:
Cognitive Control: Stroop task

Response interference condition:
Cognitive Control: Stroop task
Response interference condition:

YELLOW
Cognitive Control: Stroop task

De Houwer’s 2003 version:

“Subtractive” logic in the design:

Congruent < Semantic interference < Response interference
Cognitive Control: Stroop task

De Houwer’s 2003 version:

“Subtractive” logic in the design:
Congruent $<$ Semantic interference $<$ Response interference

Semantic Conflict as a measure of Cognitive Control
(De Houwer, 2003):
Semantic Conflict $=\text{Congruent} - \text{Semantic interference}$
Cognitive Control: Stroop task

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Semantic Conflict as a measure of Cognitive Control
(De Houwer, 2003):
Semantic Conflict = Congruent $-$ Semantic interference

But according to Brown (2011), the Congruent condition also includes facilitation effects uncorrelated with the interference effects:

“Subtractive” logic in the design:
Congruent $<$ Neutral $<$ Semantic interference $<$ Response interference
Cognitive Control: Stroop task

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Semantic Conflict as a measure of Cognitive Control
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Semantic Conflict = Neutral − Semantic interference
Cognitive Control

Is associative priming may be a special case of the general mechanism used to make predictions?
Is associative priming may be a special case of the general mechanism used to make predictions?

If so:

Cognitive Control

RT

condition
unpredictable
predictable

low mid high
Aim:

- investigate how the processing of expected and unexpected upcoming words is affected by
  - cognitive control
  - working memory capacity
  - reading skills
Experiment

Pretest

- Task: Sentence completion
- Subjects: 38
- Stimuli: 53 incomplete experimental sentences such as (3) and 57 fillers

(3) Der Bäcker schob den Teig in ...
The baker put the dough in ...

26 sentences completed with nouns with cloze probability over 0.61 where selected.
Stimuli

(4)  a. PREDICTABLE
Der Bäcker schob den Teig in seinen Ofen und wartete.
The baker put the dough in his.masc oven and waited.

b. UNPREDICTABLE/SURPRISING
Der Bäcker schob den Teig in seine Mikrowelle und wartete.
The baker put the dough in his.fem microwave and waited.
Subjects: 81

Tasks:

- assessment of individual differences
  - Adaptation of De Houwer’s (2003) Stroop task for cognitive control
  - Operation span task (Conway et al., 2005; Malsburg & Vasishth, 2012) for working memory capacity
  - Rapid automatized naming (Kuperman & Van Dyke, 2011) for reading skills
- Self-paced reading
  - Stimuli: 26 items based on the pretest such as the previous example (4) and fillers
Results of Stroop task
Stroop conditions are significantly different from each other and:

Congruent < Neutral < Semantic interference < Response interference

Figure: Visualization of LMM partial effects (Hohenstein & Kliegl, 2013)
Assessment of individual differences

- **Cognitive control** = weighted difference (using PCA) of mean speed of Semantic interference and Neutral conditions
- **Working Memory Capacity** = partial credit units (Conway et al., 2005)
- **Reading Skills** = mean speed of the rapid automatized naming task
Results

Numerical difference between the conditions at the determiner (\(\text{Coef} = 0.01, \text{SE} = 0.01, t = 0.81\))

Significant difference between the conditions at the noun in a length-corrected model (\(\text{Coef} = 0.03, \text{SE} = 0.02, t = 2.18\))
Results

- Numerical difference between the conditions at the determiner
  \( (\text{Coef} = 0.01, \ SE = 0.01, \ t = .81) \)

- Significant difference between the conditions at the noun in a length-corrected model \( (\text{Coef} = 0.03, \ SE = 0.02, \ t = 2.18) \)
Results

- no significant interactions between reading skills or working memory and condition
Results

- no significant interactions between reading skills or working memory and condition
- significant cognitive control × condition interaction \((\text{Coef} = -0.05, \text{SE} = 0.01, t = -3.61)\)

Figure: Visualization of LMM partial effects (Hohenstein & Kliegl, 2013)
Conclusions

- No significant interactions between reading skills or working memory and condition, probably because the experimental sentences were too short and simple.
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- No significant interactions between reading skills or working memory and condition, probably because the experimental sentences were too short and simple.
- Longer RTs at the unpredictable determiner (numerically) and at the noun (significant), which is consistent with the results from the literature (Van Berkum et al., 2005).
Conclusions

- Readers with less cognitive control were more affected by surprising content (his.fem)

(5)  

a. PREDICTABLE

Der Bäcker schob den Teig in seinen Ofen und wartete.
The baker put the dough in his.masc oven and waited

b. UNPREDICTABLE/SURPRISING

Der Bäcker schob den Teig in seine Mikrowelle und
The baker put the dough in his.fem microwave and
wartete.
waited
Conclusions

- Readers with less cognitive control were more affected by surprising content (his.fem).
- The results suggest that cognitive control modulates the ability to suppress irrelevant predictions (maybe prediction error?, see: Egner et al., 2010), in this case the ability to inhibit the predicted gender form (seinen) when it is not supported by evidence (seine).

(5) a. PREDICTABLE

Der Bäcker schob den Teig in seinen Ofen und wartete.
The baker put the dough in his.masc oven and waited.

b. UNPREDICTABLE/SURPRISING

Der Bäcker schob den Teig in seine Mikrowelle und wartete.
The baker put the dough in his.fem microwave and waited.
THANKS!

QUESTIONS?