Semantics and visual cognition: the processing of Bulgarian and Polish majority quantifiers

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Contribution of the experimental study:

- **Evidence:** quantifiers bias distinct strategies during timed verification of visual displays
  - **Most1:** same strategy as **English most** (Lidz et al. 2011)
  - **Most2:** different strategy due to its semantics.

- Importantly, the canonical verification strategies are used even in cases where either strategy would yield the correct truth value.

- Contribution of the individual morphemes not only to the meaning of Most1 vs Most2 but also to the interface with the visual cognition.

Background: Research Question

- The English proportional quantifier **most**
  - three truth-conditionally equivalent specifications

(1) **Most of the dots are yellow.**

(i) \(|\text{Dot}(x) \& \text{Yellow}(x)| > \frac{1}{2} |\text{Dot}(x)|\)

(ii) \(|\text{Dot}(x) \& \text{Yellow}(x)| > |\text{Dot}(x) \& \text{``Yellow''}(x)|\)

(iii) OneToOnePlus(\(|\text{Dot}(x) \& \text{Yellow}(x)|, |\text{Dot}(x) \& \text{``Yellow''}(x)|\))

- not all of (i–iii) form equally good “psychological hypotheses” about how the derived truth-conditions are verified against a visual display (Lidz et al. 2011)

Background: Experimental evidence

- **Hackl 2009**
  - self-paced counting paradigm (dots in two colors)
  - **most** and **more than a half** are processed differently
    - excluding (i) \(|\text{Dot}(x) \& \text{Yellow}(x)| > \frac{1}{2} |\text{Dot}(x)|\) as verification for **most**

Background: Experimental evidence

- **Pietroski et al. 2008**
  - even when the arrangement of dots favors verification by (iii) OneToOnePlus(\(|\text{Dot}(x) \& \text{Blue}(x)|, |\text{Dot}(x) \& \text{``Blue''}(x)|\)) it is not used

Background: Experimental evidence

- **Lidz et al. 2011**
  - \(|\text{Dot}(x) \& \text{Yellow}(x)| > |\text{Dot}(x) \& \text{``Yellow''}(x)|\)
  - How is the cardinality of the non-yellow set estimated when it is a **multicolor** set?

- **Selection strategy**
  - \(|\text{Dot}(x) \& \text{Red}(x)| \cup |\text{Dot}(x) \& \text{Blue}(x)| \cup |\text{Dot}(x) \& \text{Green}(x)| \cup \ldots|

- **Subtraction strategy**
  - \(|\text{Dot}(x)| - |\text{Dot}(x) \& \text{Yellow}(x)|

Background: Experimental evidence

- A heterogeneous set is not automatically selectable.
- Humans can automatically compute the total number of dots and **two color subsets** (Halberda et al. 2006).

- **The number of color sets should affect Selection, but not Subtraction.**
Background: Experimental evidence

• Lidz et al. 2011 – experiment: 150ms displays of dots in up to 5 colors in varying ratios (yellow to non-yellow dots).
  • Subtraction always used for the judgment of (1)
  – no difference in accuracy as the function of number of colors of dots, but only as the function of the ratio.

  Subtraction strategy
  \[ |\text{Dot}(x) \& \text{Yellow}(x)| > |\text{Dot}(x)| - |\text{Dot}(x) \& \text{Yellow}(x)| \]

• Lidz et al. 2011: Interface Transparency Thesis
  • A declarative sentence is semantically associated with a canonical procedure for the verification of its truth value that is biased towards those algorithms that directly compute the relations expressed in the meaning”.

Most1 and Most2 in Bulgarian and Polish

(3)BG
  a. Povečeto točki sa žalit. Most1 dots are yellow 'Most dots are yellow.'
  b. Naj-mnogo točki sa žalit. Most2 dots are yellow 'Yellow dots form the largest subset.'

(4)PL
  a. Większość kropek jest żółta. Most1 dots is yellow 'Most dots are yellow.'
  b. Najwięcej jest kropek żółtych. Most2 dots yellow 'Yellow dots form the largest subset.'

Materials and methods

• On-line visual-display verification study:
  • Native speakers judge whether (3-4) are true while viewing displays of arrays of dots, flashed on a computer screen for 200ms.
  • BG: n = 39, PL: n = 20

• Yellow dots were present on every display, together with
  1, 2 or 3 other distractor colors. (3 levels of distractor variable)
  • Ratios of yellow and non-yellow dots were 1:2, 2:3 or 5:6. (3 levels of ratio variable)
  • 360 displays were presented in 2 blocks (180 for Most1 and 180 Most2, half of each requiring a yes response and half a no response). Participants had 380ms to indicate their response by a button press.
**Results**

- **Most1** is verified by a *Subtraction* strategy
- accuracy rates are significantly affected only by ratio, and not by number of color sets

3x3x2 Repeated Measures ANOVA (3 levels of ratio: 5:6, 2:3, 1:2, 3 levels of distractor: 3, 2, 1; truth/falsity of screens)

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**Most1 Bulgarian**

- *Yes* on true screens
- *No* on false screens

significant effect of ratio, F(2, 76) = 173.791, p < .001
no significant effect of distractor, F(2, 76) = 3.153, p = .021
no significant effect of truth/falsity, F(1, 38) = 107, p = .425

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**Most2 Polish**

- *Yes* on true screens
- *No* on false screens

significant effect of ratio, F(2, 38) = 182.449, p < .001
significant effect of distractor F(2, 76) = 72.612, p < .001
significant effect of truth/falsity F(1, 38) = 13.533, p > .001

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**Results: Most1 vs Most2**

- **Most1**: significant effect of ratio and no significant effect of number of colors is the same as with the English most in Lidz et al. 2009.
- Most1 is thus compatible with the Subtraction verification procedure.

- **Most2**: significant effect of number of colors in addition to the effect of ratio indicate that both the yellow set and the other color sets are selected for the verification of Most2 in conformity with its semantics.
  - (accuracy affected by truth/falsity – correct estimation of both the target set and each color set is expected to be affected by a higher number of factors than Subtraction.)

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**Results: Most1 vs Most2**

- Subtraction continues to be used with Most1 and Selection with Most2 even on the two-color sets condition, where switching between the two procedures would provide more accurate results.

- Participants could have used whichever strategy is computationally less costly/more accurate under time pressure, since both strategies are otherwise used by the speakers of Bulgarian and Polish.

- If the semantic representation guides verification then with Most2 the non-yellow set should be selected directly – the accuracy should be greater than with Most1 where the non-yellow set is computed (cf. Lidz et al. 2011).
Two color condition: Most1 vs Most2 - Bulgarian

"Yes" on true screens

"No" on true screens

Most2 significantly better than Most1 on true screens (F(1, 38) = 32.970, p < .001)
On false screens Most2 significantly worse than Most1 (F(1, 38) = 4.892, p = .033)

Two color condition: Most1 vs Most2

- Both Bulgarian and Polish participants were significantly better with Most2 than Most1 on true screens.
- On false screens Most1 significantly better than Most2.

Reaction times
- On true screens Most2 is faster
  - BG: F(1, 38) = 5.87, p = .048, PL: F(1, 19) = 5.173, p = .035
- On false screens Most1 is faster
  - BG: F(1, 38) = 9.884, p = .003, PL: F(1, 19) = .351, p = .561

The two languages are behaving exactly the same: the accuracy is higher despite faster RTs and lower despite slower RTs

Conclusion – Two color condition: Most1 vs Most2

- Computation for both Most1 and Most2: comparison between the yellow and the non-yellow set. The components provided by the visual system: yellow set, non-yellow set, superset.
- Different algorithms:
  - To verify Most2: estimate target + estimate competitor
  - To verify Most1: estimate target + estimate total + subtract target from total

- The lexical meaning of the functional morphemes that build Most1 and Most2 and their logical syntax are interfacing with the visual system during the verification process.

Conclusions

1. On two color screens (where Most1 and Most2 are either both true or both false) the verification procedure depends on the lexical item used. The patterns of accuracy for Most1 and Most2 were conspicuously different (same direction in both Bulgarian and Polish) – computationally Most1 and Most2 are different.

- Our experiments indicate that semantics provides inviolable instructions to visual cognition processes.
- The results confirm and extend the findings of Pietrosi et al. (2008), Hackl (2009), Litz et al. (2011)

References:

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