

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

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Lidz et al. (2011) argue that the lexical semantics of quantifiers is transparently associated with a canonical procedure for verification of truth/falsity. They show that sentences such as (1) are uniquely associated with truth conditions and a verification procedure involving subtraction (2), despite the availability of other semantically equivalent specifications (e.g. 3).

- (1) Most of the dots are yellow.
- (2) $|\text{Dot}(x) \ \& \ \text{Yellow}(x)| > |\text{Dot}(x)| - |\text{Dot}(x) \ \& \ \neg\text{Yellow}(x)|$
- (3) $|\text{Dot}(x) \ \& \ \text{Yellow}(x)| > |\text{Dot}(x) \ \& \ \text{Red}(x)| + |\text{Dot}(x) \ \& \ \text{Blue}(x)| + |\dots|$

I provide further experimental evidence that quantifier semantics is transparently associated with a canonical verification strategy. My evidence is based on the comparison of the verification patterns of two minimally distinct majority quantifiers, and suggests that the properties of the linguistic input directly influence the unconscious visual processes. It is not just psychophysics that precludes the use of Selection for the visual verification of the quantifier *most*.

I tested the processing of two majority quantifiers in Bulgarian (Bg) and Polish (Pl): the counterpart of English *most* (*povečeto* in Bg, *większość* in Pl, henceforth Most1) and a closely related quantifier with the meaning of “the largest subset” (*naj-mnogo* in Bg, *najwięcej* in Pl, henceforth Most2). I obtained three notable results:

- Most1 is verified by a Subtraction strategy as in (2) and not (3), directly replicating the findings of Lidz et al. for Slavic;
- Most2 is verified by a Selection strategy as in (4) in accordance with its lexical semantics;
- the canonical verification strategies are used even in cases where either strategy would yield the correct truth value.

- (4) $|\text{Dot}(x) \ \& \ \text{Yellow}(x)| > |\text{Dot}(x) \ \& \ \text{Red}(x)|,$
 $\ \& \ |\text{Dot}(x) \ \& \ \text{Yellow}(x)| > |\text{Dot}(x) \ \& \ \text{Blue}(x)|,$
 $\ \& \ |\text{Dot}(x) \ \& \ \text{Yellow}(x)| > |\text{Dot}(x) \ \& \ \text{Green}(x)|, \ \& \ \dots$

Lidz et al. (2011) hypothesize that the Selection procedure in (3) is not plausible for psychophysical reasons. It involves selection of each individual color set in order to obtain the cardinality of the non-yellow set. In view of the evidence from Halberda et al. (2006) that multiple color sets can be enumerated in parallel, but only for the total set of dots and two-color subsets, the procedure in (3) should be computationally costly if the verification involves more than one non-yellow set. The subtraction procedure in (2), on the other hand, is independent of the number of color sets and thus more suitable as a general verification strategy for the quantifier *most*.

My evidence suggests that (3) could be psychologically available as a procedure for visual verification, because a computationally similar procedure, (4), is employed by the speakers of Bulgarian and Polish when verifying Most2.

The results have some immediate implications for the semantics of quantifiers and the interface of semantics with visual cognition. We can argue for the contribution of the individual

morphemes not only to the meaning of Most1 vs. Most2 but also to the interface with the visual cognition. The combined Bulgarian and Polish results further strengthen my conclusions based on Polish in Tomaszewicz (2011).

In my visual verification task native speakers of Bulgarian (n=39) and of Polish (n=20) evaluated the truth of (1) against 200ms displays of colored dots, where the ratio of the target to the rest and the number of color sets were manipulated. For Most1 accuracy rates were significantly affected only by ratio, and not by number of color sets (5a,c). For Most2 accuracy rates were significantly affected both by ratio and number of color sets (5b,d).

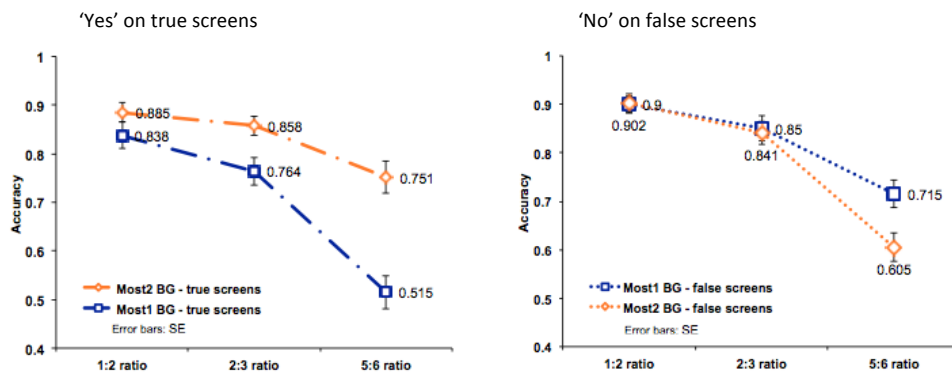
(5) Accuracy rates			ratio					color sets			
			1:2	2:3	5:6			2	3	4	
(a)	Bulgarian	Most1 (<i>povečeto</i>)	.858	.778	.643	p<.001		.764	.748	.767	p=.321
(b)		Most2 (<i>naj-mnogo</i>)	.827	.742	.617	p<.001		.807	.731	.648	p<.001
(c)	Polish	Most1 (<i>większość</i>)	.871	.785	.673	p<.001		.797	.763	.769	p=.215
(d)		Most2 (<i>najwięcej</i>)	.866	.76	.63	p<.001		.801	.767	.688	p<.001

Since Subtraction in (2) does not depend on the number of distractor color sets, its computational cost remains the same as the number of distractors increases. Selection in (3, 4), does become more computationally costly. The results for Most1 and Most2 are consistent with the verification strategies in (2) and (4), respectively. Most1 is not verified by Selection in (3), although it is a psychologically plausible strategy given its similarity to (4).

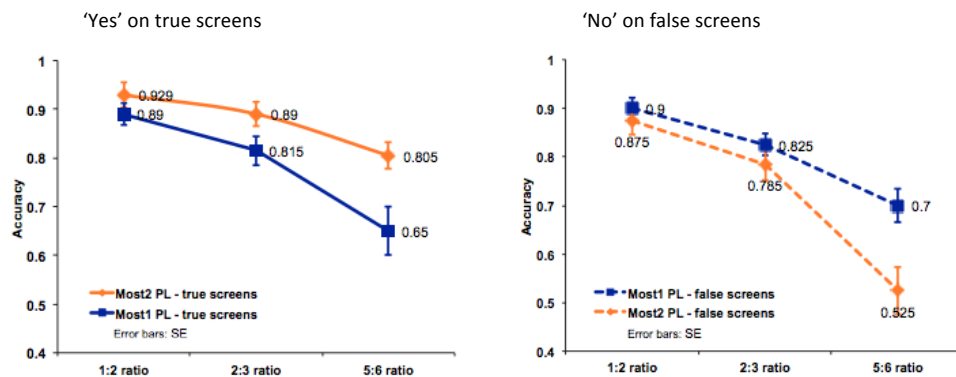
Is Subtraction used for Most1 because it is always more efficient? Importantly, on screens with 2 color sets (identical for both quantifiers) both Bulgarian and Polish participants were significantly less accurate and slower confirming the truth of Most1 than of Most2. This indicates that Subtraction continues to be used with Most1 and Selection with Most2 even on the 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), which is exactly what we find on the “true screens”.

(5) Two-color condition: Most1 vs Most2 in Bulgarian



(6) Two-color condition: Most1 vs Most2 in Polish



Both Bulgarian and Polish participants were significantly better with Most2 than Most1 on true screens (Bulgarian ($F(1, 38) = 32.970, p < .001, F(1, 19) = 10.49, p = .004$). On false screens Most1 is significantly better than Most2 (Bulgarian ($F(1, 38) = 4.892, p = .033$, Polish ($F(1, 19) = 11.122, p = .003$).

Notably, the two languages also behave exactly the same with respect to the reaction times. The accuracy is higher despite faster RTs and lower despite slower RTs. On true screens Most2 is faster (Bulgarian ($F(1, 38) = .587, p = .448$, Polish ($F(1, 19) = 5.173, p = .035$). On false screens Most1 is faster (Bulgarian ($F(1, 38) = 9.884, p = .003$, Polish ($F(1, 19) = .351, p = .561$). The RT data shows that it is not the case that people were more prone to errors as they were making judgments faster. Instead, we can see that the procedure with Most2 on true screens is easier (faster, more accurate judgments) which is expected if the two color sets are selected directly.

Crucially, the accuracy patterns together with RTs consistent in both languages indicate that participants do not switch to the more advantageous strategy, e.g. they don't use Selection to more accurately confirm the truth of Most1. This is the more interesting given the findings of Halberda et al. (2006) that the cardinality of two color sets is automatically computed. Yet the semantics of Most1 apparently precludes the use of this automatically available information.

Different behavior with each quantifier on the very same two-color screens indicates that participants do not switch between the procedures and that the way those procedures differ is specified by the semantics. Computation for both Most1 and Most2 involves the comparison between the yellow and the non-yellow set. The components provided by the visual system are exactly the same: yellow set, non-yellow set, superset. However, the algorithms must be different. To verify Most2 one has to (i) estimate the target, (ii) estimate the competitor, (iii) compare. To verify Most1 one needs to (i) estimate the target, (ii) estimate the total, (iii) subtract the target from the total, (iv) compare. The accuracy patterns and the RT data suggest that the lexical meaning of the functional morphemes that build up Most1 and Most2 and their logical syntax are interfacing with the visual system during the verification process.

In conclusion, my experiments indicate that semantics provides a direct set of instructions to the visual cognition processes, and that these instructions are followed even when computationally more advantageous strategies are available. Importantly, in a within-subject design the same

group of participants behaves differently depending on the quantifier. The overall patterns of accuracy are exactly the same in Bulgarian and Polish.

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 are conspicuously different (and have the same direction in both Bulgarian and Polish) indicating that computationally Most1 and Most2 are different.

My results confirm and extend the findings of Pietroski et al. (2008), Hackl (2009), Lidz et al. (2011) and indicate that semantics provides inviolable instructions to visual cognition processes.

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