Verification Procedures for Modified Numeral Quantifiers

A Self-Paced Counting Study

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Summary

This poster presents a Self-Paced Counting study of verification procedures for modified numeral quantifiers (*more than n*, *at least n*, *fewer than n, at most n*). The aim is to investigate to what extent the form of a quantifier determines its associated verification strategies. We show that the numeral *n* affects the counting component of the verification process, that the modifier (*more*, *at least*, …) affects the decision stage, and that these two factors do not interact. Such effects are difficult to reconcile within Generalized Quantifier Theory, which analyzes modified numeral quantifiers as quasi-idiomatic expressions.

Motivation

Quantifiers play a central role in syntax and semantics because they introduce foundational questions about the inventory of combinatorial processes and the expressive power found in natural language. Despite the importance of quantifiers to linguistic theorizing, little is known about how quantifier meanings are processed in real time, specifically how their truth conditional import is used by non-linguistic systems of the mind in verification tasks.

Generalized Quantifier Theory

The predominant framework for studying quantifiers is articulated within Generalized Quantifier Theory (GQT). According to GQT the basic semantic building blocks for quantification in natural language are relations between sets of individuals (Barwise&Cooper 1981).

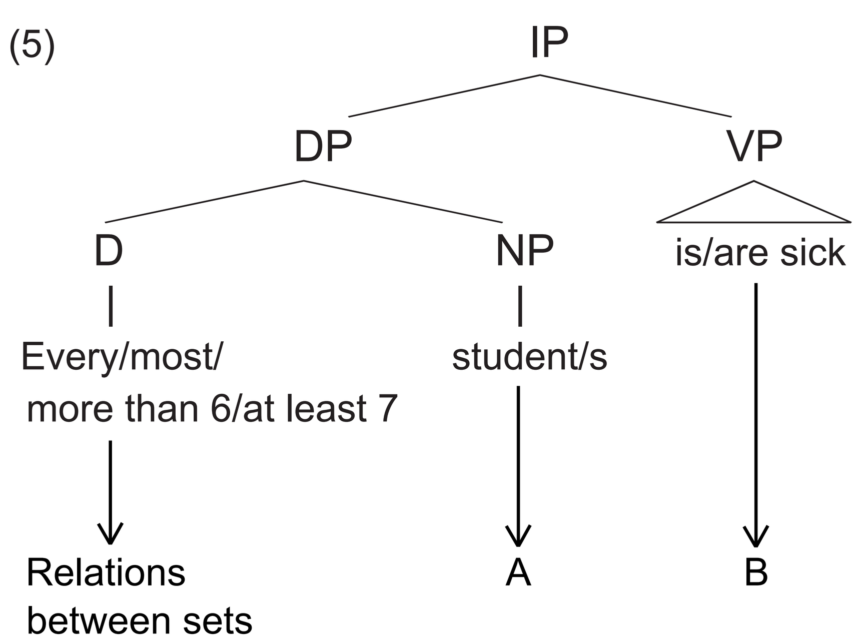
(1) [[Every]] (A)(B) = 1 iff $A \subseteq B$

(2) [[Most]] (A)(B) = 1 iff $|A \cap B| > |A - B|$

(3) [[More than 6]] (A)(B) = 1 iff $|A \cap B| > 6$

(4) [[At least 7]] (A)(B) = 1 iff $|A \cap B| \geq 7$

(5)



Coarseness of GQT

Assuming that relations between sets are semantic primitives yields a framework that is too coarse to exploit differences in the internal make-up of quantifiers.

(6) [[More than six/At least seven]] (A)(B) = 1 iff $|A \cap B| > 6$

(7) [[More than six/At least seven]] (A)(B) = 1 iff $|A \cap B| \geq 7$

(8) [[Less than seven/At most six]] (A)(B) = 1 iff $|A \cap B| < 7$

(9) [[Less than seven/At most six]] (A)(B) = 1 iff $|A \cap B| \leq 6$

Can we distinguish between formally different but denotationally equivalent ways of stating the truth-conditional import of quantifiers?

Monotonicity of Modified Numeral Quantifiers

More than six/at least seven are monotone increasing quantifiers while *less than seven/at most six* are monotone decreasing quantifiers. For any A, A', B, B' where $A \subseteq A'$ and $B \subseteq B'$

(10) [[More than six/At least seven]] (A)(B) $\models$ [[More than six/At least seven]] (A')(B')

(11) [[Less than seven/At most six]] (A')(B') $\models$ [[Less than seven/At most six]] (A)(B)

Verification Procedures for Quantified Statements

Assuming that the linguistic make-up of a modified numeral quantifier affects its associated verification strategies, one might expect an effect of the type of modifier (monotone increasing, monotone decreasing), an effect of the number mentioned (n, n+1), and possibly an interaction. This leads to the following experimental set-up.

	n	n+1
Mono. ↑	more than	at least
Mono. ↓	at most	less than

Predictions of GQT

If the verification procedure is informed by truth-conditions only, the effect of counting to the critical number (N), the point at which the truth-values switch, should be constant across all four conditions, while the number mentioned (n) should not have an effect.

Predictions of a Decompositional Approach

If the verification procedure is informed by component parts within the quantifier, we expect to see an effect when n is reached, whether or not N has been seen. In addition, since the direction of the switch (true to false, or false to true) is determined by monotonicity (increasing determiners become true while decreasing ones become false), we would expect an effect of monotonicity as N is reached.

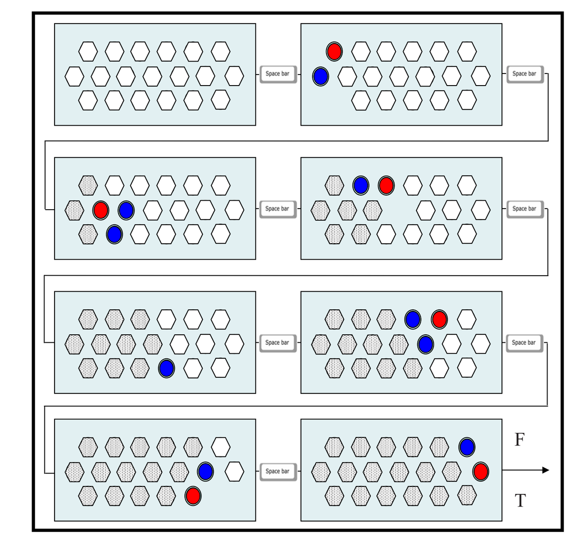
Experimental Design

In order to investigate whether the modifier and the numeral affect verification and whether the effects are independent of each other, we studied verification procedures triggered by sentences as in (12).

(12) a. More than 6 of the dots are red.
b. At least 7 of the dots are red.
c. At most 6 of the dots are red.
d. Fewer than 7 of the dots are red

The critical point (N) at which the truth-value switches is the same across all four conditions: 7th red dot: *more than 6/at least 7* become true, *most 6/fewer than 7* become false.

Self-Paced Counting Methodology



- Subjects hear a sentence ("more than six of the dots are red") and are asked to determine as fast and as reliably as possible its truth/falsity relative to an array of dots.
- Arrays are presented as three scattered rows of hexagonal plates, (figure 1, screen 0).
- As participants press the space bar, dots are uncovered in groups of 1, 2, or 3, while previously seen dots are recovered and masked.
- Participants may answer once they have enough information.

Experiment 1: *Monotonicity*

- 120 target items: 30 *more than*, 30 *at least*, 30 *fewer than*, 30 *at most* varied evenly by truth (60 true/ 60 false) and number of target dots (40 n = 6/7/8)
- Dot arrays varied in length between 16 and 19
- Targets were presented with 288 filler items and 10 practice items.

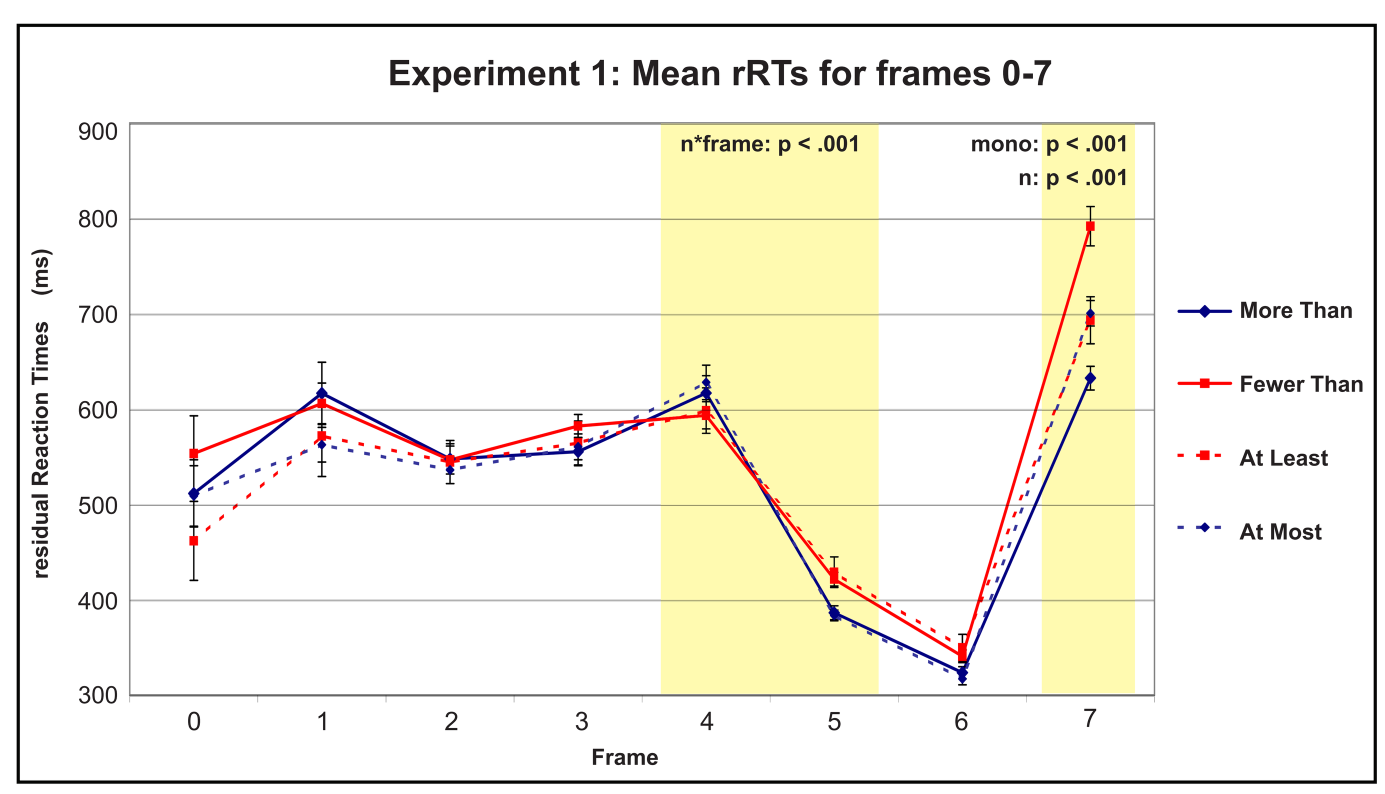
- Frame 4: N-1 dots are seen (which is number heard (n) for *more than n* and *at most n*)
- Frame 5-6: no target dots are presented (leading to the decrease in rRTs)
- Frame 7: the truth value was determined by the presence or absence of a final dot

Experiment 2: *Monotonicity Answers*

The purpose of Experiment 2 is to investigate whether the effect of monotonicity is specific to truth such that monotone increasing quantifiers are easier to verify than to falsify, whereas monotone decreasing quantifiers are easier to falsify than to verify. In Experiment 1, truth was systematically correlated with the presence or absence of a final target dot. In order to avoid this confound, answer frames in Experiment 2 are consistent across all items and truth is determined by a difference in n.

Analysis and Results

- Only RTs from correct answers of subjects with $\geq$ 80% correct answers.
- Repeated measures ANOVA with factors "Determiner (Det)" and "Screen."



Experiment 1: *Results*

Frames 4-5

Interaction frame by n ($F(1,24) = 29.078$; $p < .001$): Frame 4, *more than/at most* (n = N-1) have increased response times compared to *at least /fewer than*, (n = N). On frame 5, the opposite is true.

Frame 7 (answer frame)

Main effect of n ($F(1,24)=13.228$; $p = .001$), where *fewer than, at least* take longer

Main effect of monotonicity ($F(1,24)=17.809$; $p < .001$), such that decreasing quantifiers take longer.

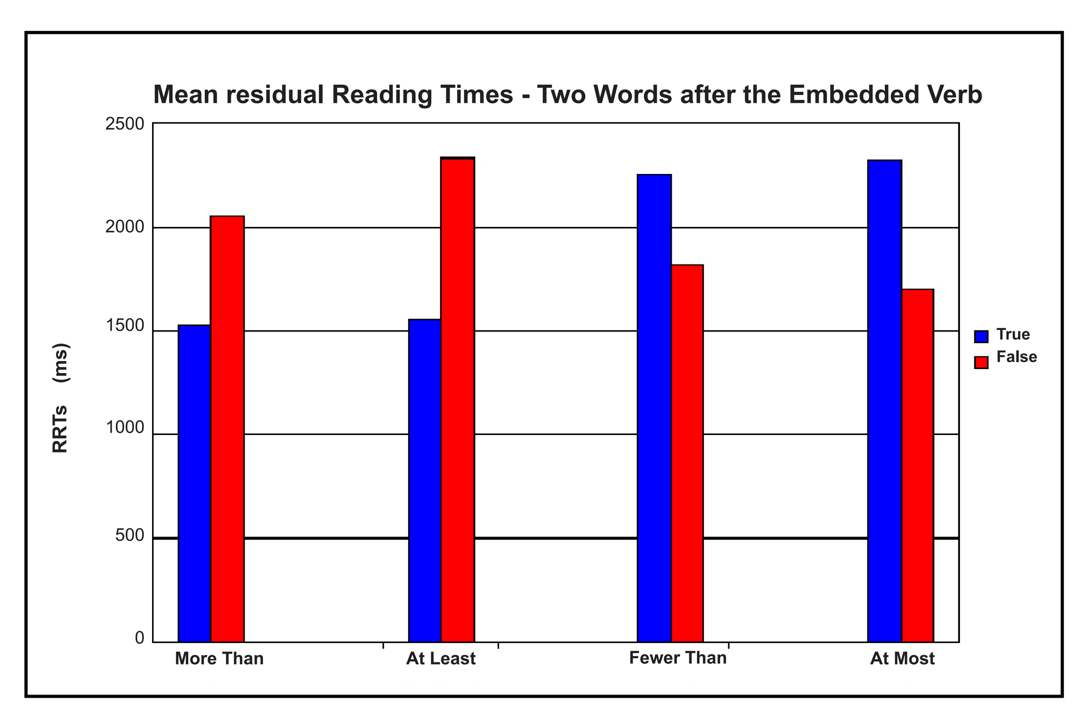
Experiment 2: *Materials*

- We kept arrays consistent across determiners st. *more than 6/7 at least 7/8 fewer than 8/7 at most 7/6* were compared for truth and falsity with out adding the confound of an additional dot
- Frame 5, no systematic gap without target dots
- Frame 6, N-2 dots are seen, n is not reached
- Frame 7, 1 or 2 target dots are seen
- Arrays and design were otherwise identical to Experiment 1

Experiment 2: *Results*

Frame 7 (Answer Frame)

Interaction of monotonicity by truth ($p < .05$), where monotone increasing (*more than, at least*) take longer to falsify, while monotone decreasing *(fewer than, at most*) take longer to verify



Discussion and Conclusion:

We observe an effect of number mentioned (n) as opposed to an effect of the critical number (N) during the counting stage. We also observe an effect of monotonicity and an effect of n at the decision stage, but no interaction between these two factors.

- GQT is too coarse to explain an effect of n, rather than N.
- A more fine-grained theory of quantification, which recognizes the number mentioned as an independent piece of modified numeral quantifiers, is required.

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Support for this research was provided by NSF Grant 0642748