The Processing of Polar Quantifiers Coupled with Negation

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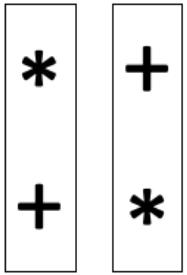
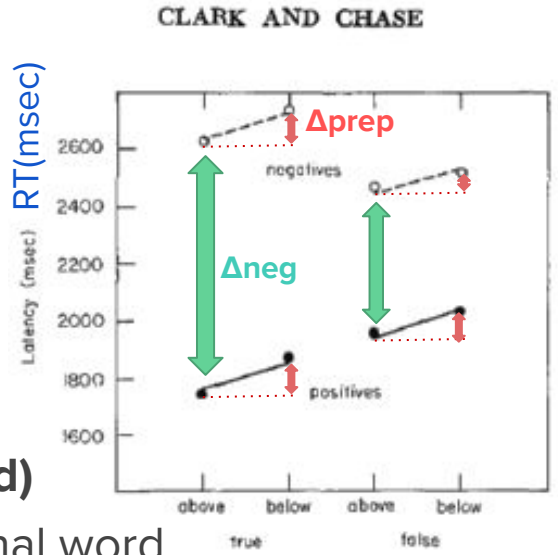
The psycholinguistic landscape: Verification with negation and true-false scenarios

a. Star is above plus
b. Star isn't above plus
c. Star is below plus
d. Star isn't below plus





- Participants took longer to verify conditions **(b)** , **(d)**
- BUT: Not a big surprise, as these have an additional word

Main goal: to study negation without added words

Main vehicle: expressions whose meaning (*but not form*) contains a negation

Clark and Chase 1972

Polarity in natural language

- Adjectives: *tall* vs. *short*
- Verbs: *believe* vs. *doubt*
- Nouns: *majority* vs. *minority*
- Quantifiers: *more* vs. *less*

Main goal: to study negation without added words

Main vehicle: expressions whose meaning (*but not form*) contains a negation

Negation reverses the direction of entailment

a function *f* is **upward entailing** if ∀ A, B in the domain of *f* such that A ⊆ B, then *f*(A) ⊆ *f*(B).
a function *f* is **downward entailing** if ∀ A, B in the domain of *f* such that A ⊆ B, then *f*(B) ⊆ *f*(A).

{x: x is blue and small} ⊆ {x: x is blue}

Some circles are blue.
∃
⇑
Some circles are blue and small.

Nuclear scope is **upward** entailing.

No circles are blue.
¬∃
⇓
No circles are blue and small.

Nuclear scope is **downward** entailing.

The polar quantifiers: *more* v.s. *less*

{x: x is blue and small} $\subseteq$ {x: x is blue}

More than half of the circles are **blue**

$\Uparrow$

More than half of the circles are **blue and small**

Nuclear scope is **upward** entailing.

Less than half of the circles are **blue**

$\Downarrow$

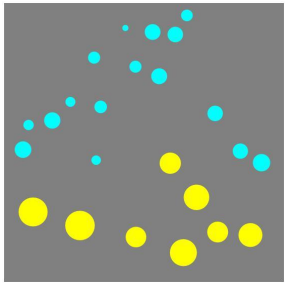
Less than half of the circles are **blue and small**

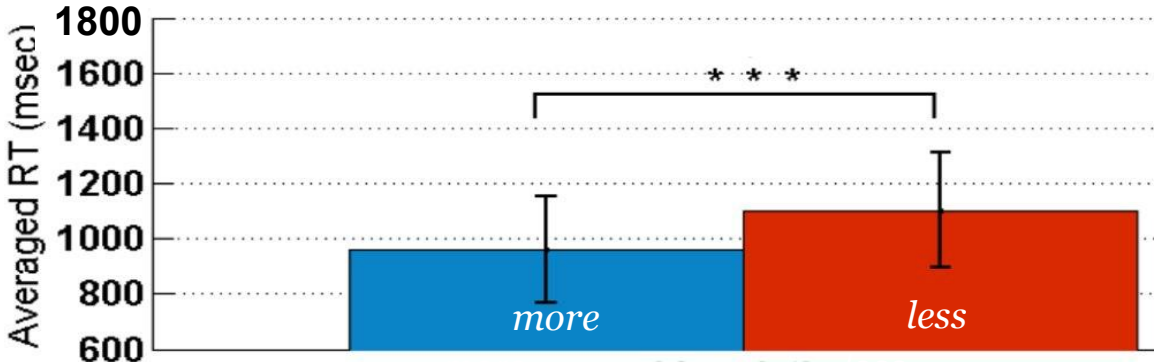
Nuclear scope is **downward** entailing.

less $\approx \neg$ more

Less takes longer to process than *more*

More than half of the circles are **blue**.
Less than half of the circles are **yellow**.





- However, we can't tell whether the processing difficulty comes from presence of negation or downward monotonicity.

Deschamps et al. 2015. *Cognition.*

Our solution: double-negation

What will be the processing cost in the case that two negations co-occur in one sentence?

- Hypothesis I : the processing cost is cumulative. That is, more negations, more processing difficulty.
- Hypothesis II : the overall monotonicity decides the cost of processing. Downward entailment makes the processing difficult. Two negations cancel each other.

Explicit negation + implicit negation

More than half of the circles are **blue**. TRUE

יותר מחצי מהעיגולים הם כחולים

Less than half of the circles are **yellow**. TRUE

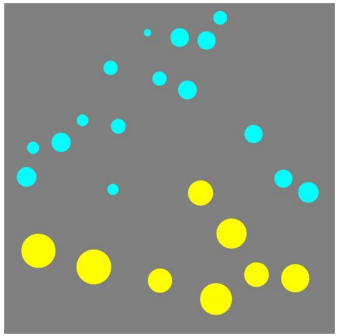
פחות מחצי מהעיגולים הם צהובים

Not more than half of the circles are **yellow**. TRUE

לא יותר מחצי מהעיגולים הם צהובים

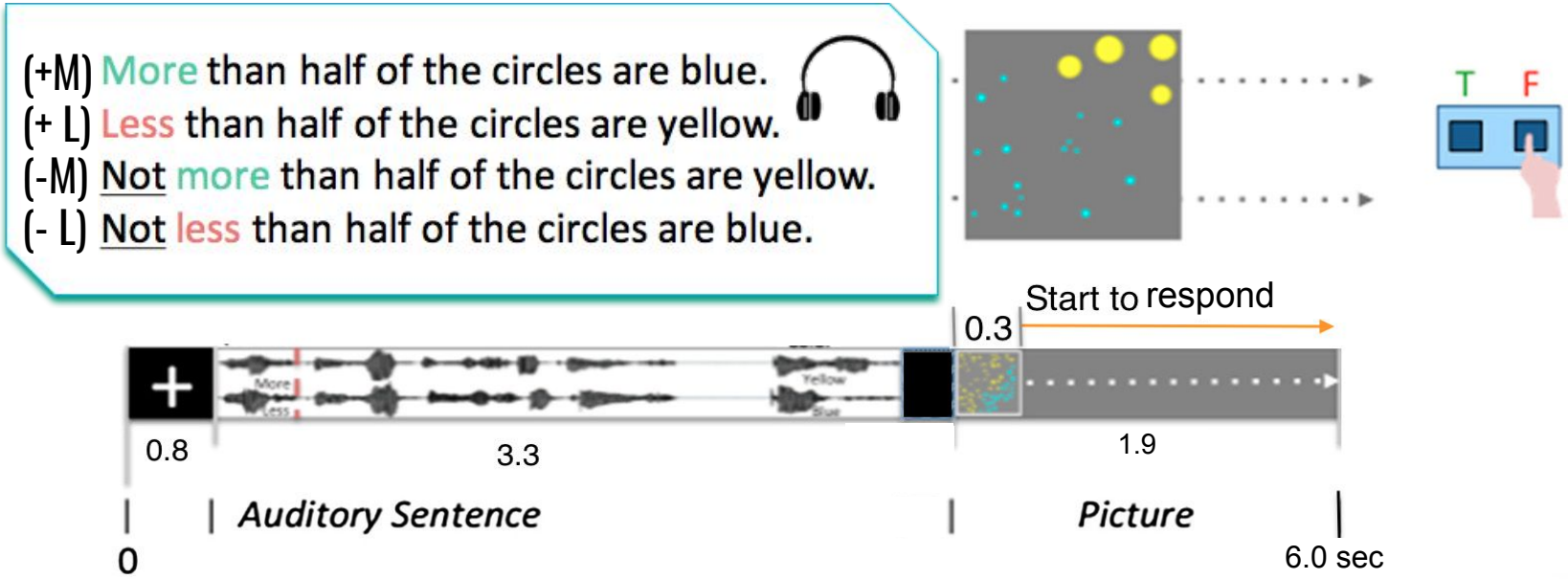
Not less than half of the circles are **blue**. TRUE

לא פחות מחצי מהעיגולים הם כחולים



Number of Negations	- Neg	+ Neg
More	(+M) **0**	(-M) **1**
Less	(+L) **1**	(-L) **2**

Experiment - Speeded Sentence Verification Task



Hypothesis I – Cumulative Model

less than half ≈ not [more than half]

not [less than half] ≈ not [not [more than half]]

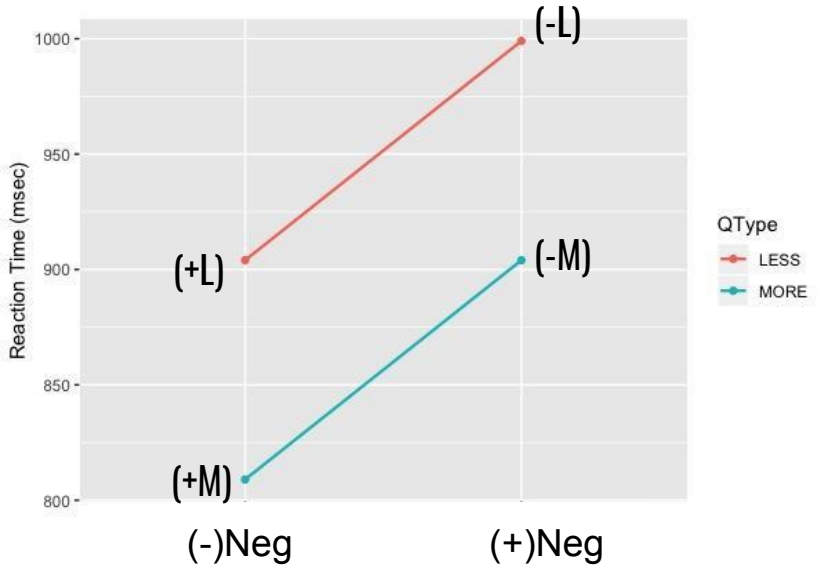
(+M) More than half of the circles are blue.

(+ L) Less than half of the circles are yellow.

(-M) Not more than half of the circles are yellow.

(- L) Not less than half of the circles are blue.

Number of Negations	- Neg	+ Neg
More	(+M) **0**	(-M) **1**
Less	(+L) **1**	(-L) **2**



Hypothesis II – Monotonicity Model

less than half ≈ not [more than half]

not [less than half] ≈ not [not [more than half]]

= [more than half]

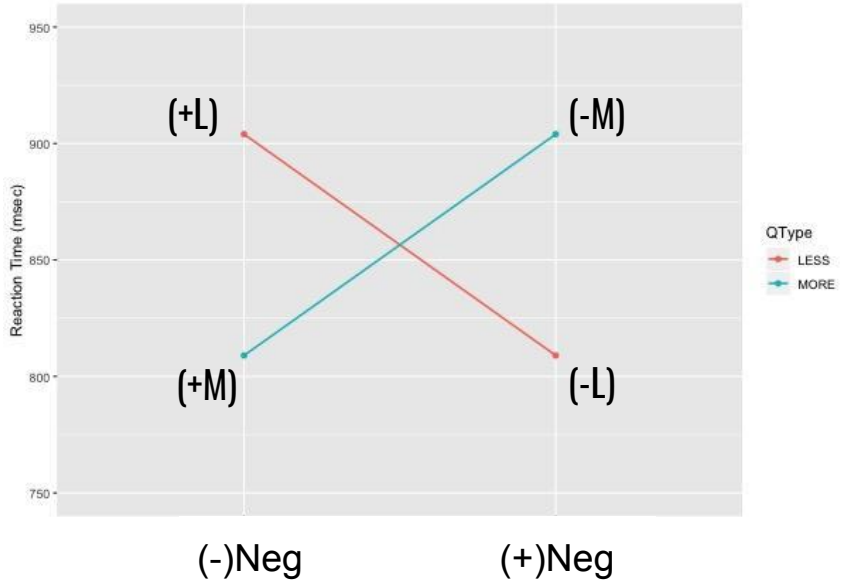
(+M) More than half of the circles are blue.

(+ L)Less than half of the circles are yellow.

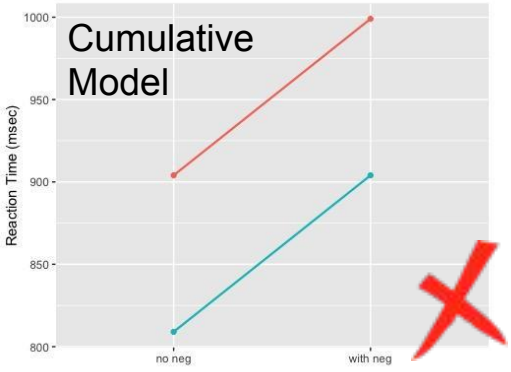
(-M) Not more than half of the circles are yellow.

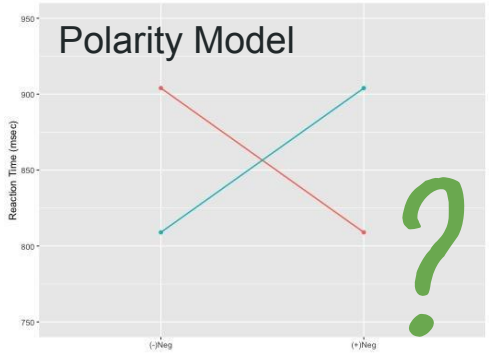
(- L) Not less than half of the circles are blue.

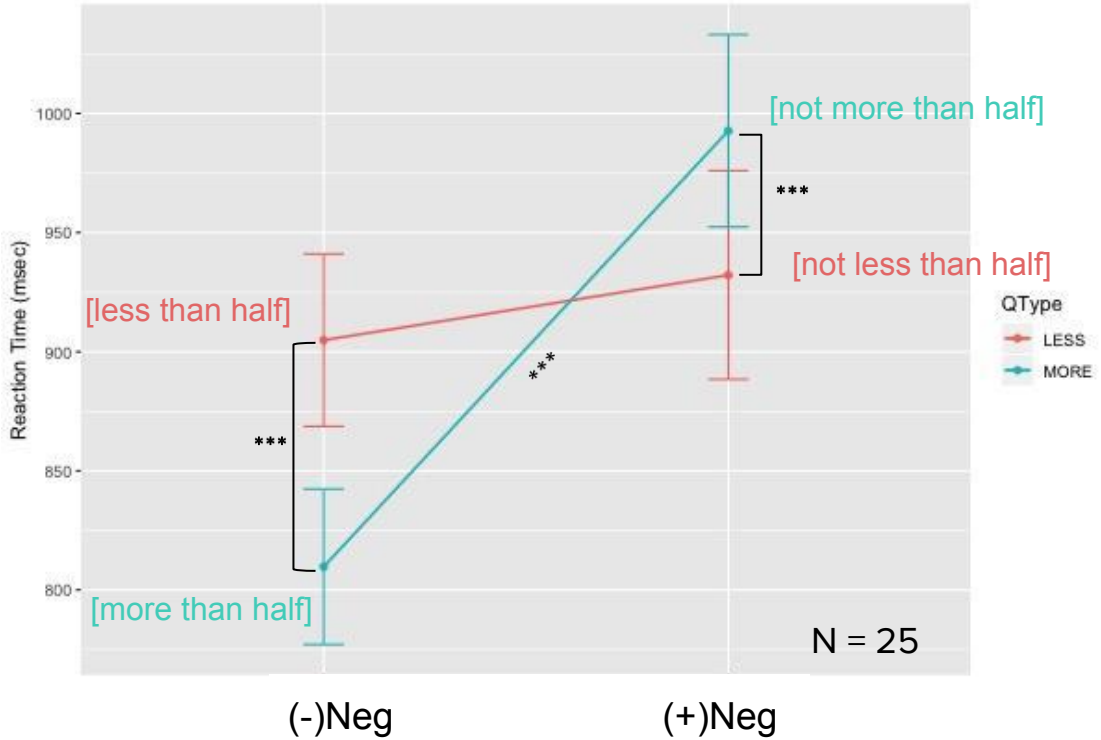
Monotonicity	without Neg	with Neg
More	(+M) **Upward**	(-M) **Downward**
Less	(+L) **Downward**	(-L) **Upward**



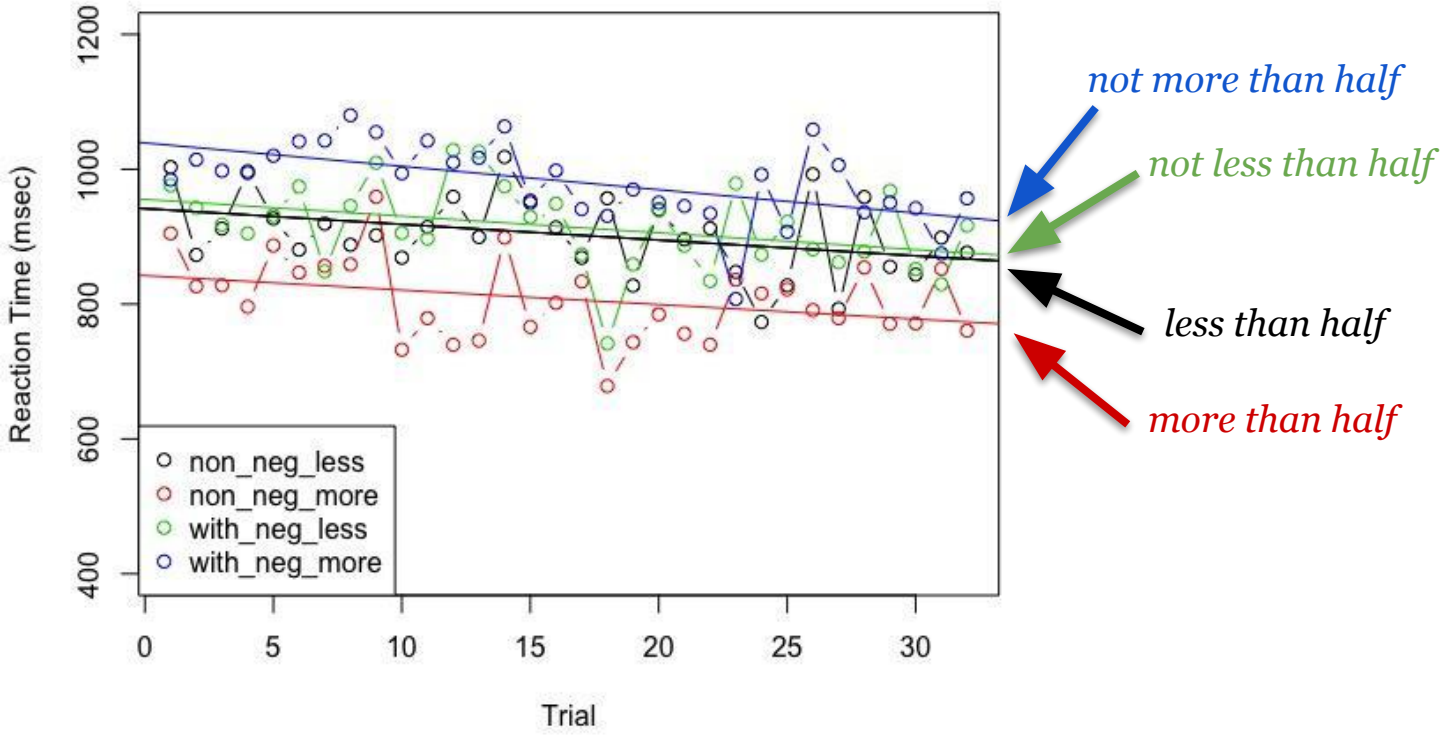
Results


Cumulative Model
Reaction Time (msec)
1000
950
900
850
800
no neg
with neg


Polarity Model
Reaction Time (msec)
950
900
850
800
750
(-)Neg
(+)Neg


Reaction Time (msec)
1000
950
900
850
800
[not more than half]
[not less than half]
[less than half]
[more than half]
***
***
***
QType
LESS
MORE
N = 25
(-)Neg
(+)Neg

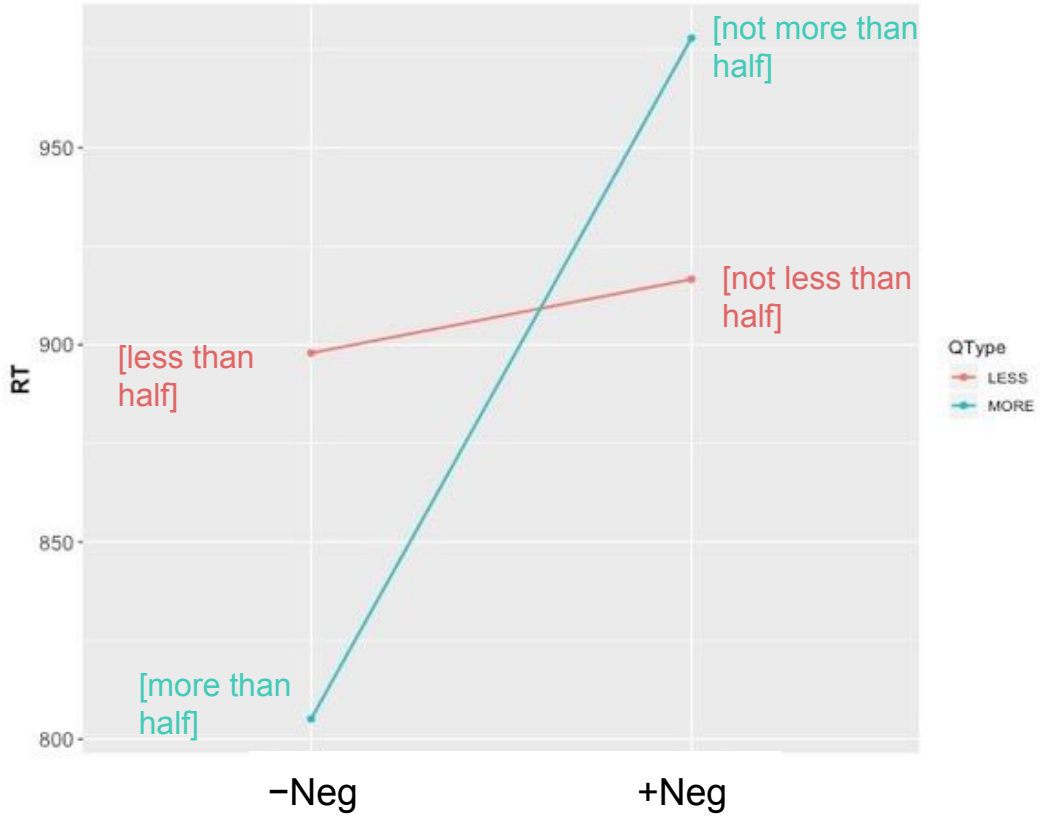
Timeplot of Reaction Time with Regression Lines



Discussion - questions of interest

Why is downward monotonicity cognitively more costly? (Q1)

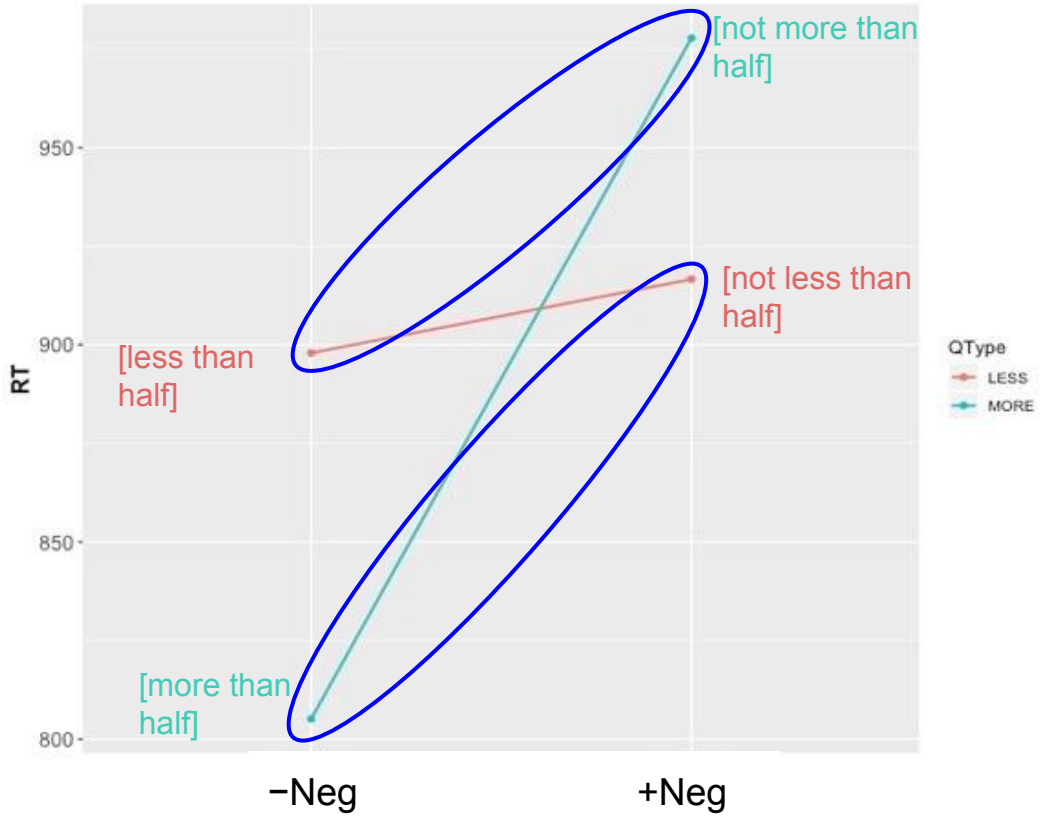
Why are +Neg items cognitively more costly? (Q2)



Discussion - questions of interest

Why is downward monotonicity cognitively more costly?

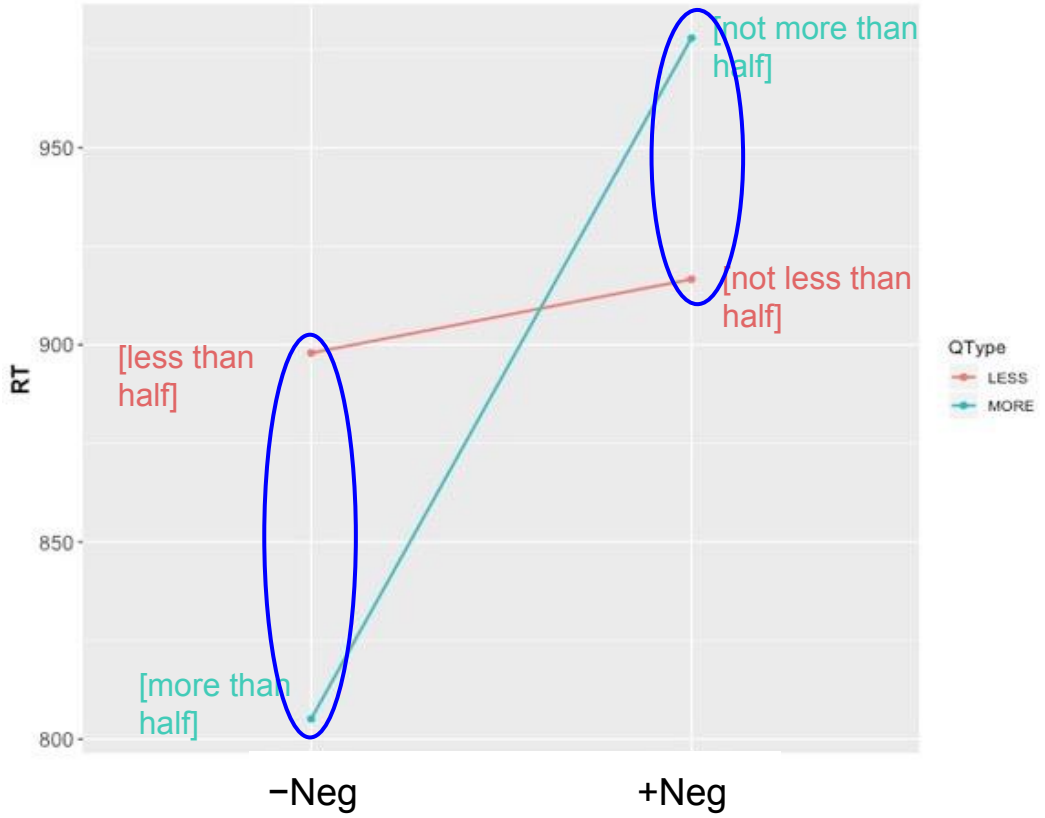
Verification cost?



Discussion - questions of interest

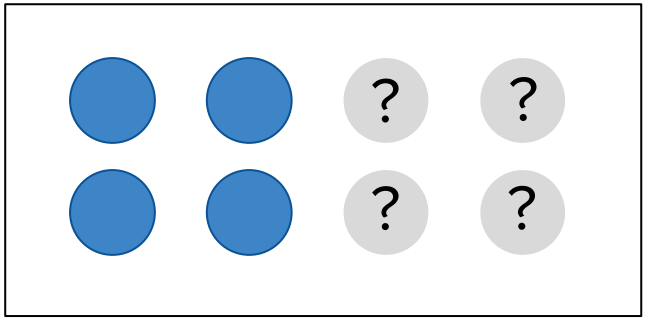
Why are +Neg items cognitively more costly?

- Complexity of comparison?
- Implicatures?

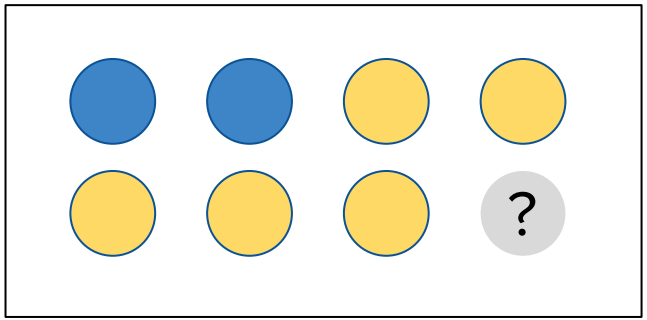


Cost of DEness: Verification cost

B&C: UE quantifiers and DE quantifiers come apart when we look at how much sampling is necessary for their verification.



"More than 3 circles are blue" can be known to be true given a sample of just 4 blue circles.



"Fewer than 3 circles are blue" cannot be known to be true until the sample covers all of the dots in the scenario.

Barwise and Cooper 1981

Cost of DEness: Verification cost

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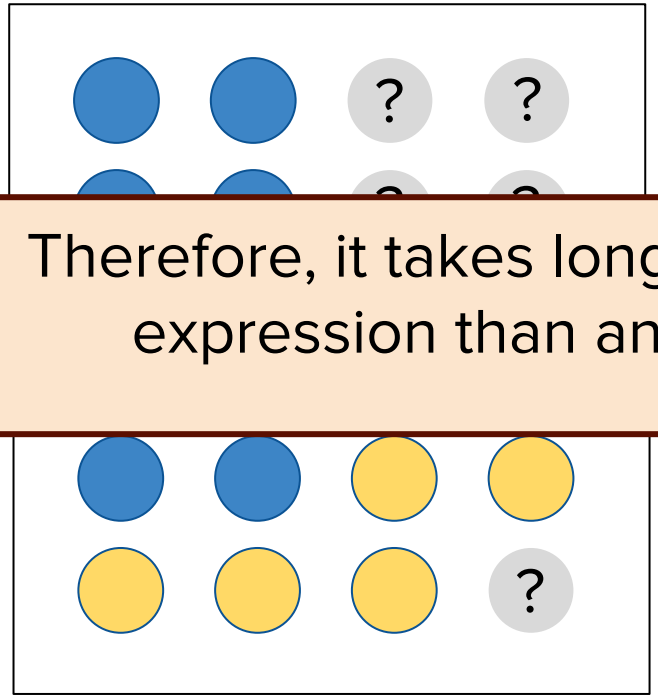


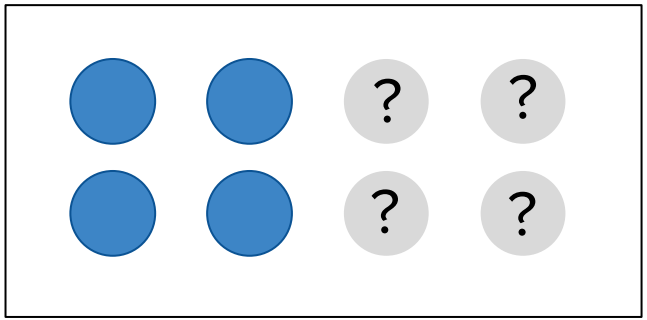
"More than 3 circles are blue" can be known to be true given a sample of just 4 blue circles.

Therefore, it takes longer to verify a downward entailing expression than an upward entailing expression.

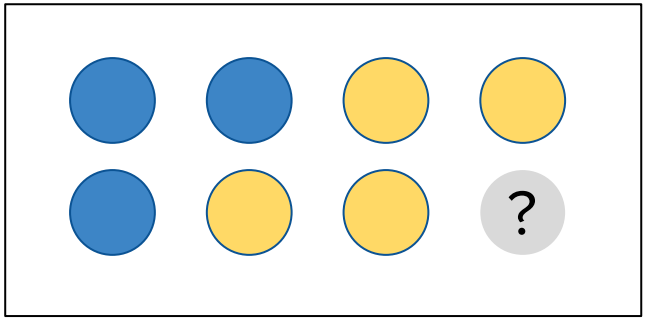
"Fewer than 3 circles are blue" cannot be known to be true until the sample covers all of the dots in the scenario.

Barwise and Cooper 1981

Cost of UEness: Falsification cost



“Fewer than 3 circles are blue” can be known to be false given a sample of just 4 blue dots.



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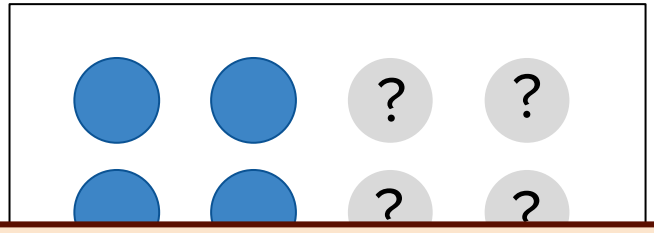
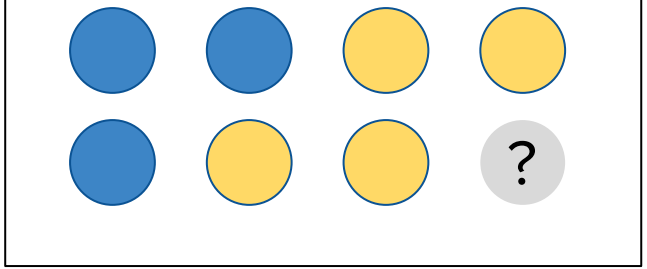


"Fewer than 3 circles are blue" can be known to be false given a sample of just 4 blue dots.

Therefore, it takes longer to falsify an upward entailing expression than a downward entailing expression.



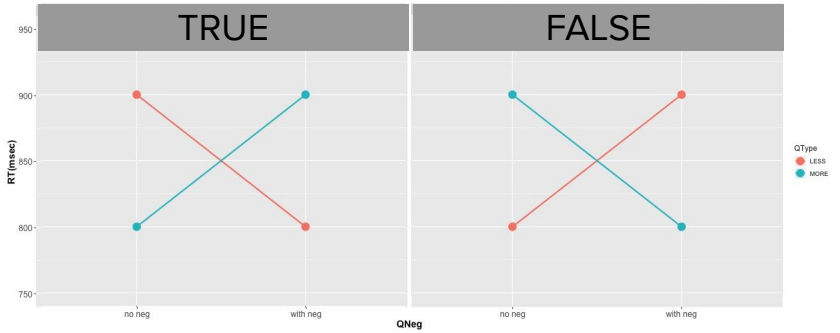
"More than 3 circles are blue" cannot be known to be false until the sample covers all of the dots in the scenario.

Cost of verification/falsification:

Predictions:

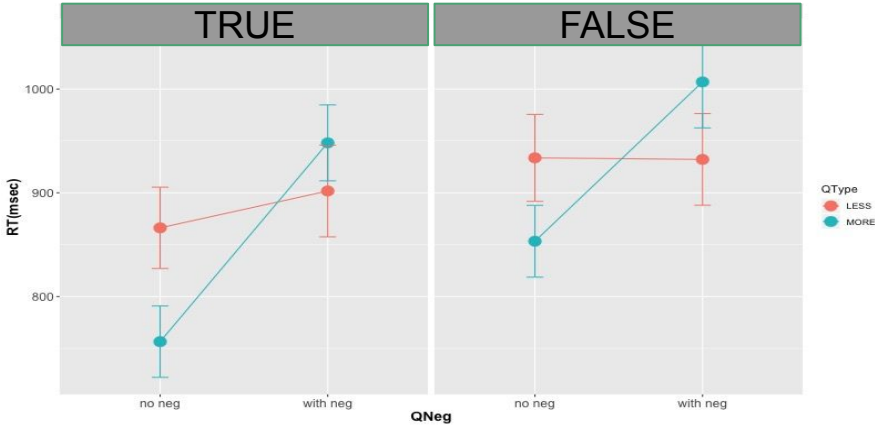
In TRUE scenarios: $RT_{UE} < RT_{DE}$

In FALSE scenarios: $RT_{UE} > RT_{DE}$



Results:

- Second prediction not borne out by our data!
- The monotonicity effect persists across the TRUE/FALSE distinction

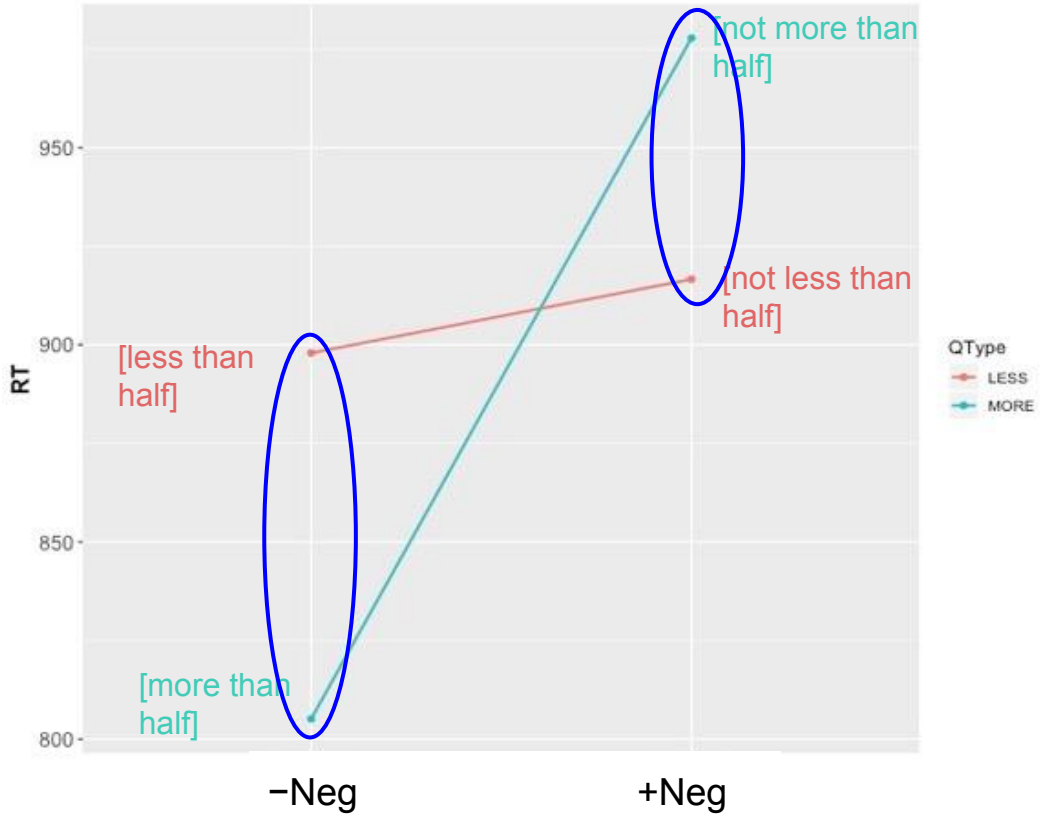


Why is DEness pervasively more costly?

- We just saw that cost of DEness ≠ cost of verification.
- From the failure to explain the cost of DEness indirectly, we conclude that it is the logical property of DEness itself that causes additional cost.
- But we have to leave the answer to the why question open.

Q2 : Why is +Neg costly?

- Complexity of the comparison?
- Scalar implicature?



Complexity of the comparison

So far, we said: less $\approx \neg$ more

To be more precise: less = $\neg \geq$

Surface	more than half	less than half	not more than half	not less than half
Logic	$> 1/2$	$\neg \geq 1/2$	$\neg > 1/2$	$\neg\neg \geq 1/2$
Equivalences	$> 1/2$	$< 1/2$	$\leq 1/2$	$\geq 1/2$

Thus, the +Neg quantifiers and only the +Neg quantifiers require an equality check in addition to an inequality check.

Hypothesis: The equality check induces a cost.

Scalar implicature

Strict comparatives don't license scalar implicatures:

- More than half of the circles are yellow
  *SI: ¬more than two thirds of the circles are yellow

Nouwen (2007): Non-strict comparatives can induce scalar implicatures:

- Not more than half of the circles are yellow
  Literal meaning + SI: exactly half of the circles are yellow
- Not less than half of the circles are blue
  Literal meaning + SI: exactly half of the circles are blue

Hypothesis: The +Neg quantifiers induce scalar implicatures, and scalar implicature computation comes with a cost.

Conclusion

- We devised an experiment to measure the cost of explicit negation, implicit negation, and their combination.
- We found:
  - no cost cumulativity when explicit negation is combined with implicit negation
  - a monotonicity effect: DEness comes with a higher cost than UEness
  - that explicit negation seems to come with a higher cost than implicit negation/no negation.
- We argued that:
  - the monotonicity effect cannot be explained by the cost of verification/falsification
  - the apparent cost of explicit negation can be traced back to the cost of non-strict comparison.
- Further exploration is necessary to identify
  - why downward monotonicity is costly
  - the exact source of the cost of non-strict comparison.