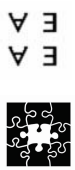
Quantifiers and Working Memory

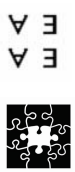
Jakub Szymanik

Joint work with Marcin Zajenkowski

Amsterdam Colloquium 2009



Outline



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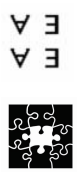
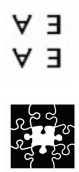


Baddeley's model

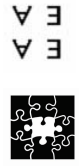
WM unified system responsible for the performance in complex tasks.

- The model consists of:
  - temporary storage units:
    - phonological loop;
    - visual loop;
  - a controlling system (central executive).

Baddeley, Working memory and language: an overview, 2003



Span test



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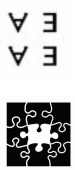
- Subjects read sentences.



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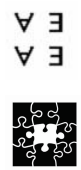
- Engagement of processing and storage functions.

Daneman and Carpenter, Individual differences in working memory, 1980

‘Computational’ theory of WM

Observation

A trade-off between processing and storage functions.



‘Computational’ theory of WM

Observation

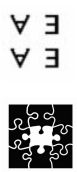
A trade-off between processing and storage functions.

Hypothesis

One cognitive resource – competition for a limited capacity.

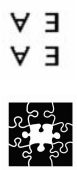
Daneman and Merikle, Working memory and language comprehension, 1996

Outline



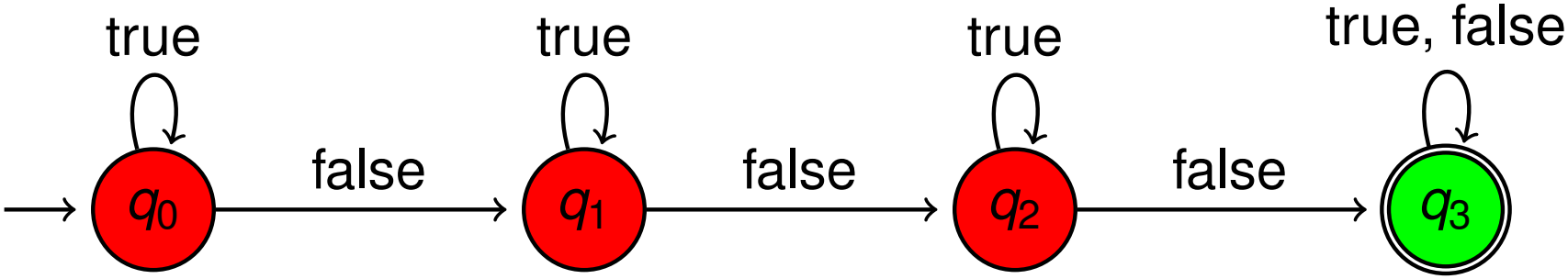
Quantifiers determine expressivity

- All poets have low self-esteem.
- Some dean danced nude on the table.
- At least 3 grad students prepared presentations.
- An even number of the students saw a ghost.
- Most of the students think they are smart.
- Less than half of the students received good marks.



Cardinal quantifiers

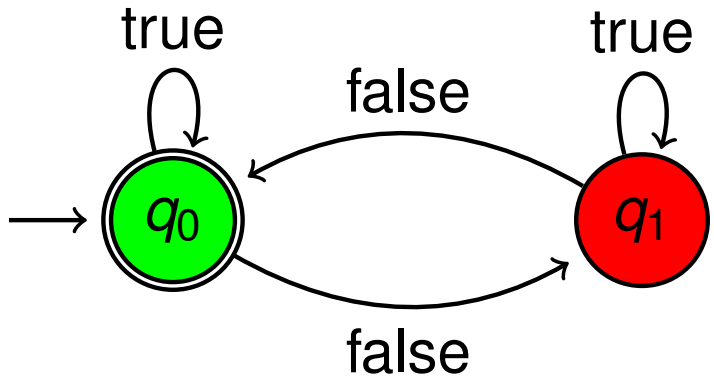
E.g. “at least 3”, “at most 7”, and “between 8 and 11”



At least 3 propositions are false.

Parity quantifiers

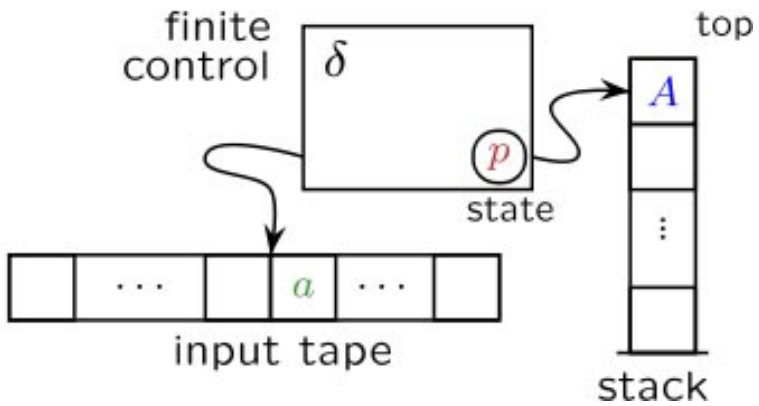
E.g. “an even number”, “an odd number”



An even number of the propositions in my paper is false.

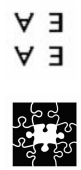
Proportional quantifiers

- E.g. “most”, “less than half”, “one third”
- There is no finite automaton recognizing those quantifiers.
- We need internal memory.
- A push-down automata will do.



Previous investigations

Differences in brain activity.



Previous investigations

Differences in brain activity.

RT increases along with the computational resources.


McMillan et al., Neural basis for generalized quantifiers comprehension, 2005


van Benthem, Essays in logical semantics, 1986


Szymanik and Zajenkowski, Comprehension of Simple Quantifiers, 2009

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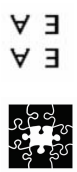
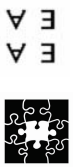


Experimental setup

Question

How additional memory load influences quantifier verification?



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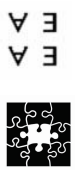
Combined task:

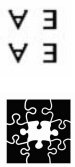
- memorize sequences of digits;
- verify quantifier sentences;
- recall digits.



Predictions

Difficulty (RT and accuracy) should decrease as follows:

- proportional quantifiers,
- numerical quantifiers of high rank,
- parity quantifiers,
- numerical quantifiers of low rank.



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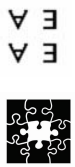
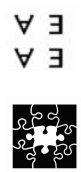
Additionally:

- processing of the PQs should influence storage functions;
- the effect should be stronger in more demanding situation.



Participants

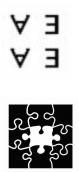
- 60 native Polish-speaking adults (42 females).
- The mean age: 24 years (SD = 4.75).
- Each participant tested individually.



Sentence verification

64 grammatically simple propositions in Polish, like:

1. More than 7 cars are blue.
2. An even number of cars is yellow.
3. Less than half of the cars are black.



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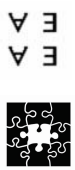

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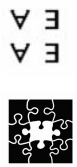
  3. parity quantifiers, DQ;



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  4. proportional quantifiers, PQ.

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Sentence verification: stimuli

More than half of the cars are yellow.

An example of a stimulus used in the sentence verification task

Memory Task

- At the beginning of each trial a sequence of digits.

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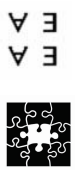
- 2 experimental conditions:
  - 4 digits
  - 6 digits



Memory Task

- At the beginning of each trial a sequence of digits.
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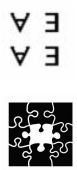
- After verification task: recall the string.



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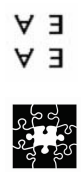
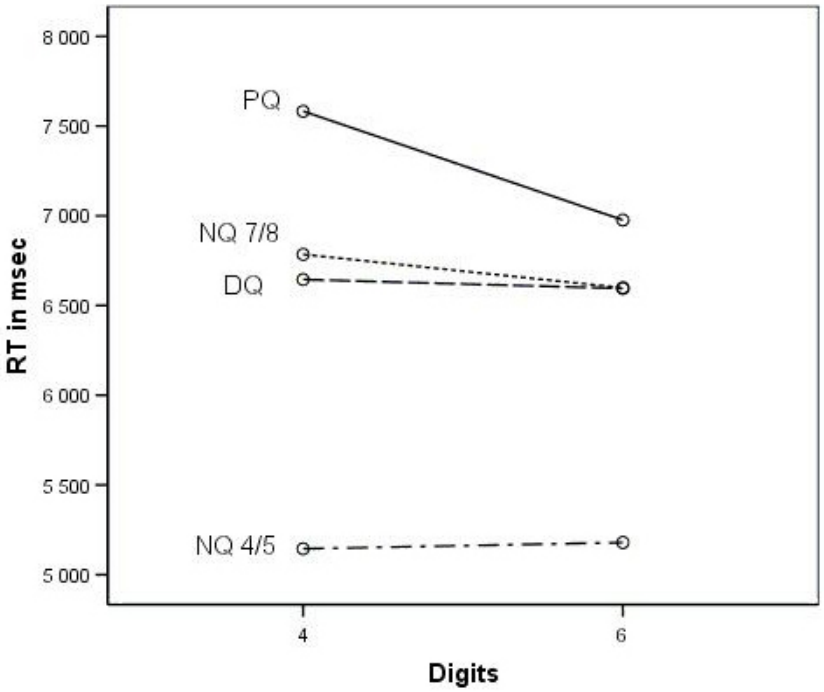


RT in verification task



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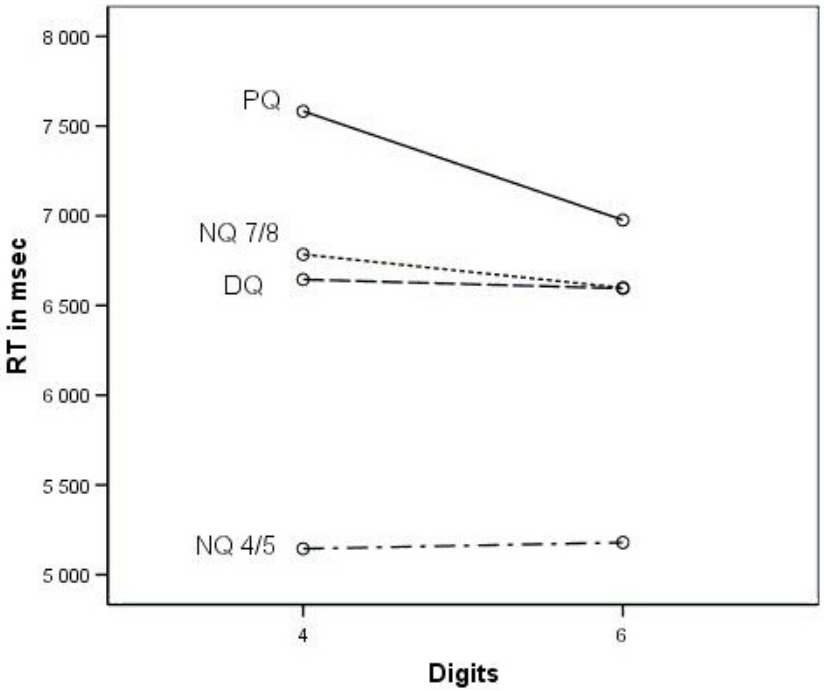

RT determined by quantifier type in 4-digit:

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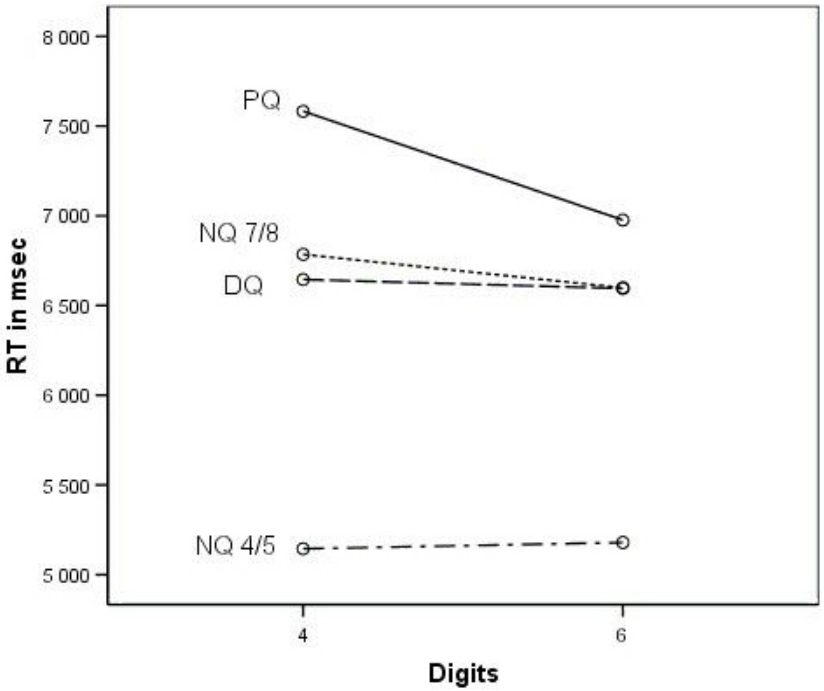

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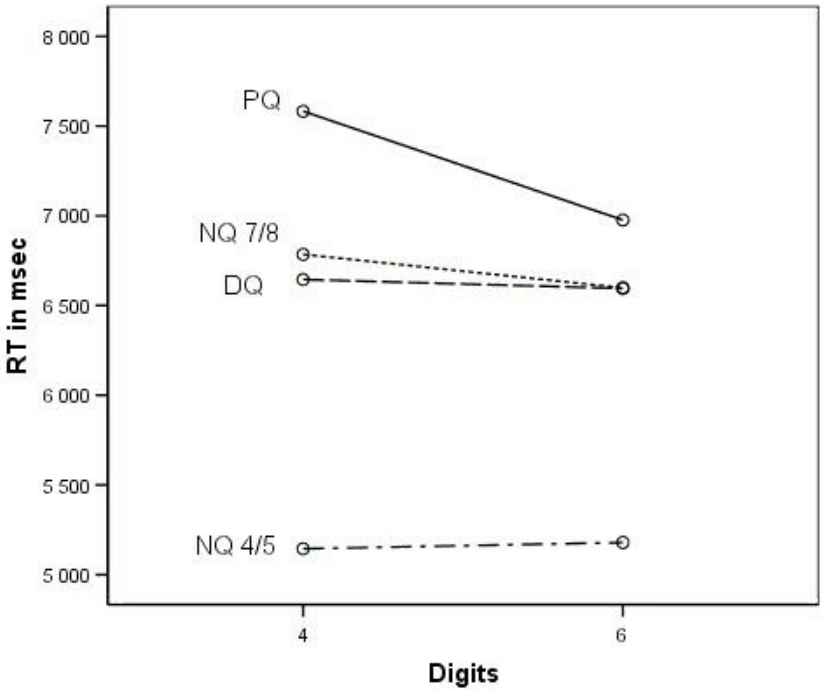

RT determined by quantifier type in 4-digit:

- PQ solved longer than others;
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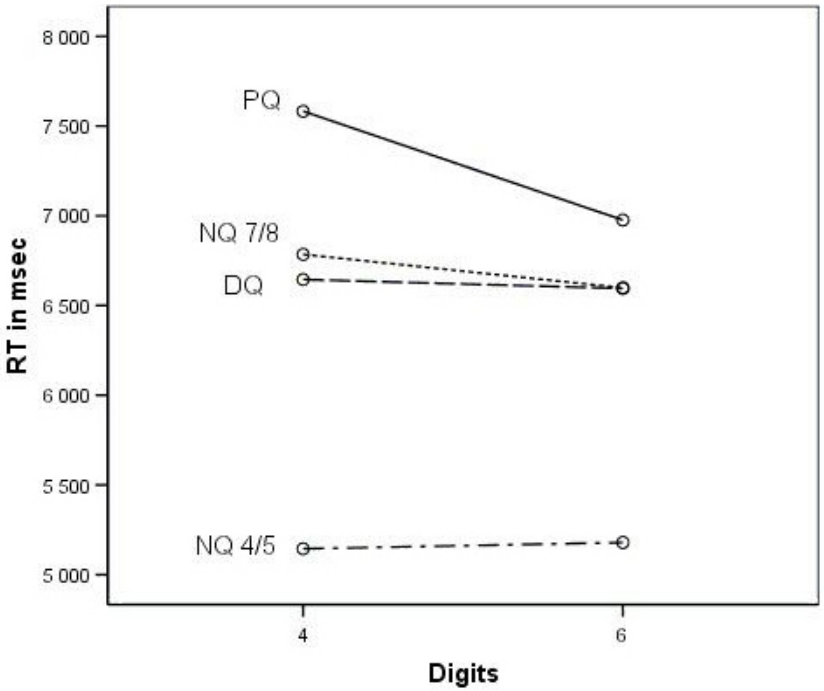
RT in verification task



RT determined by quantifier type in 4-digit:

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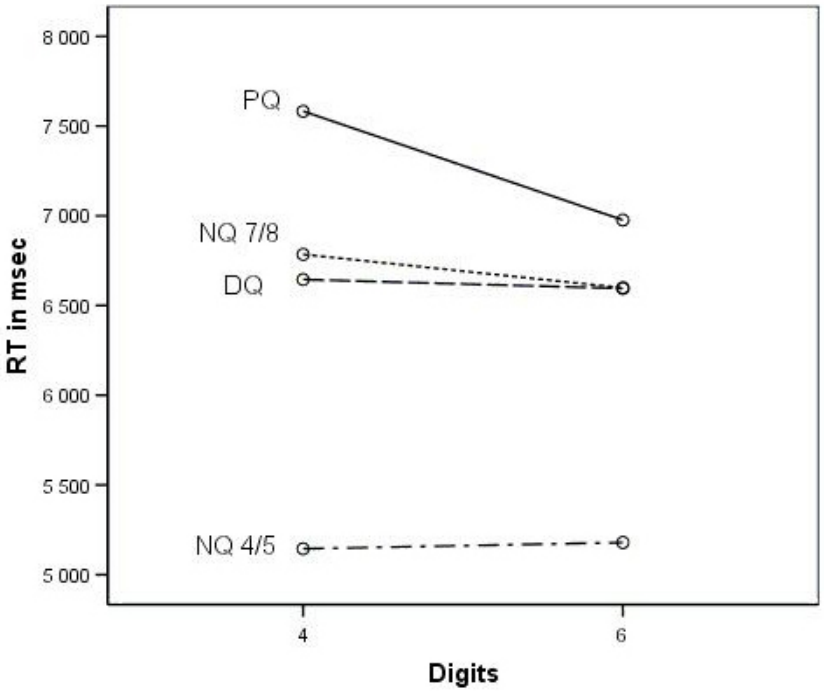
RT in verification task



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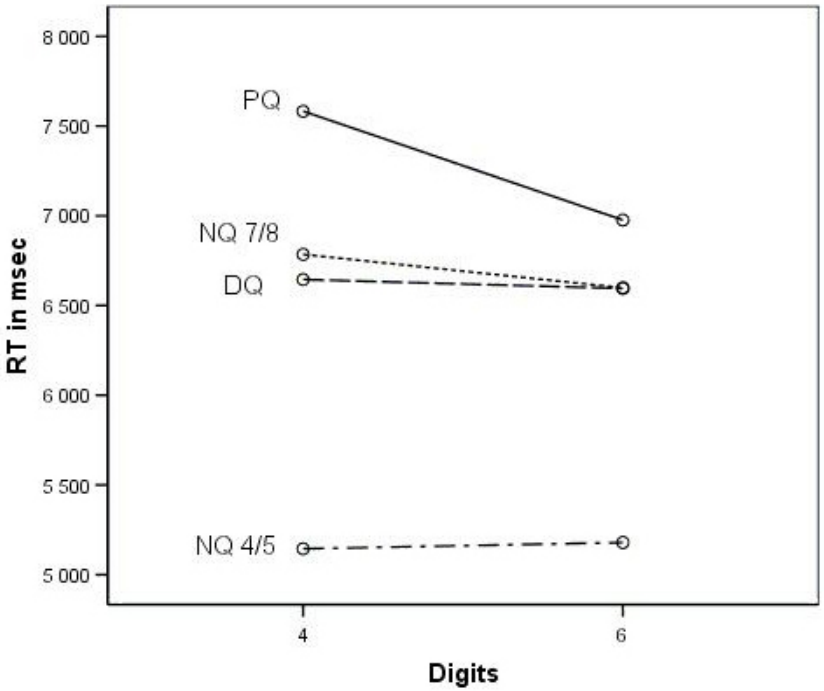
6-digit condition:

RT in verification task



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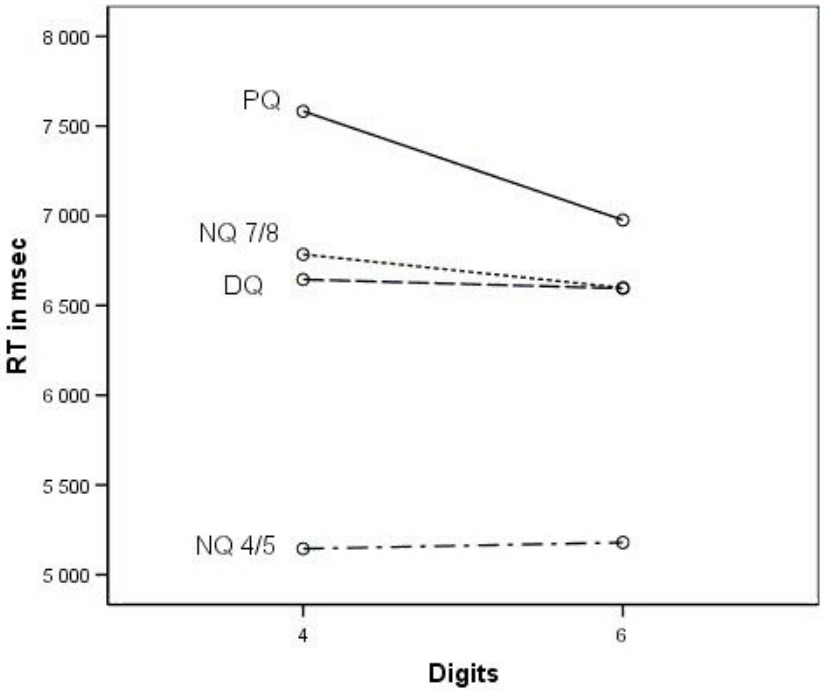
- NQ 4/5 had the shortest average RT.

RT in verification task



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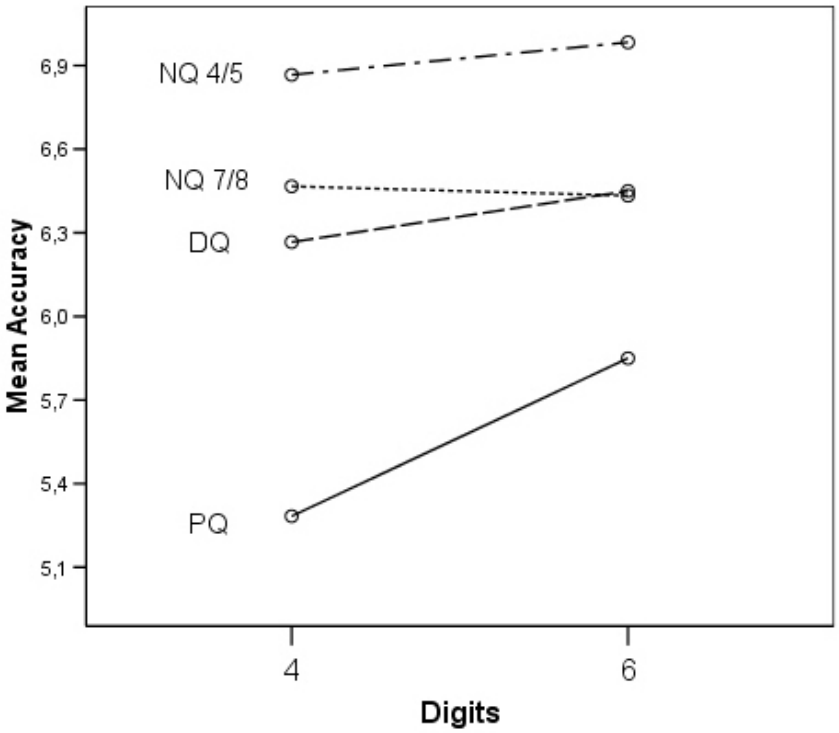
Only PQ differed between memory load conditions.

Accuracy in verification task



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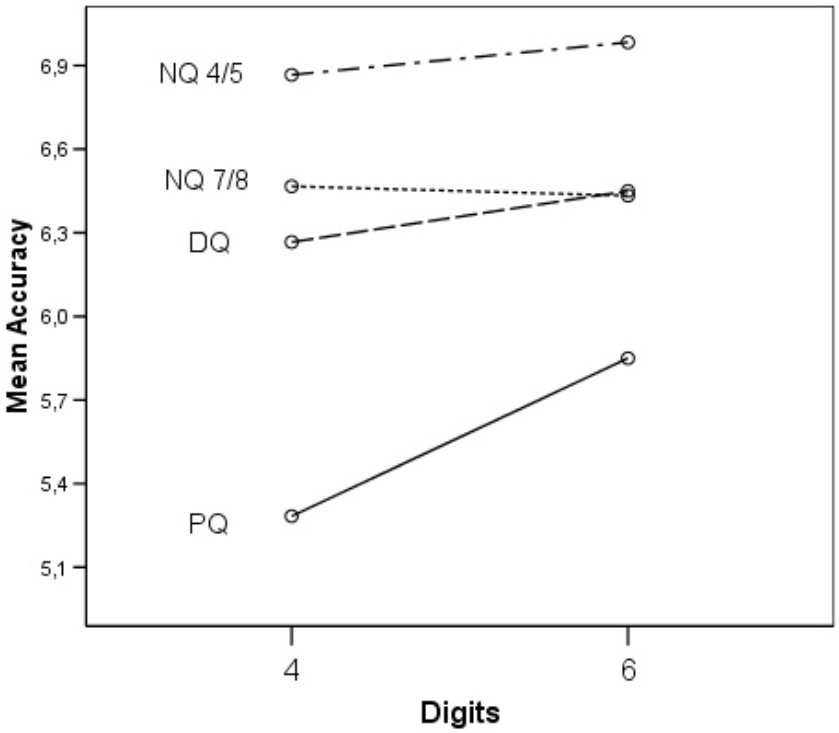

- All quantifiers differed significantly,
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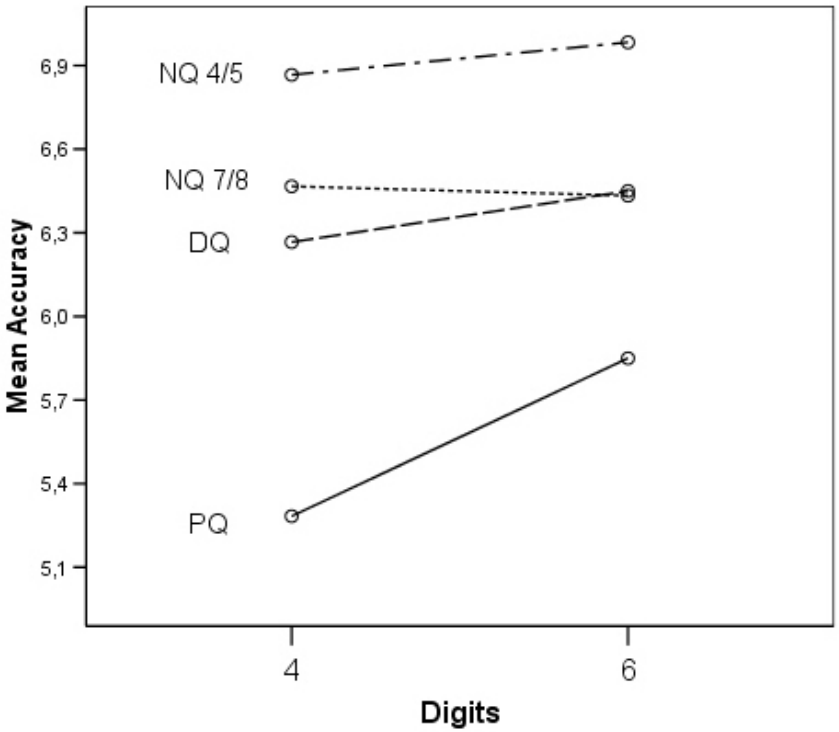

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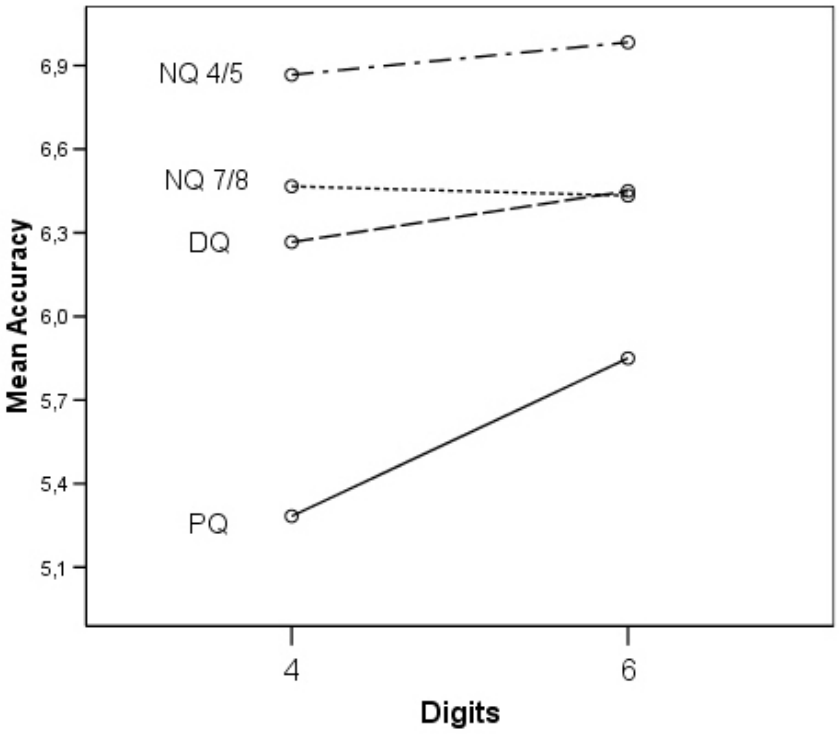

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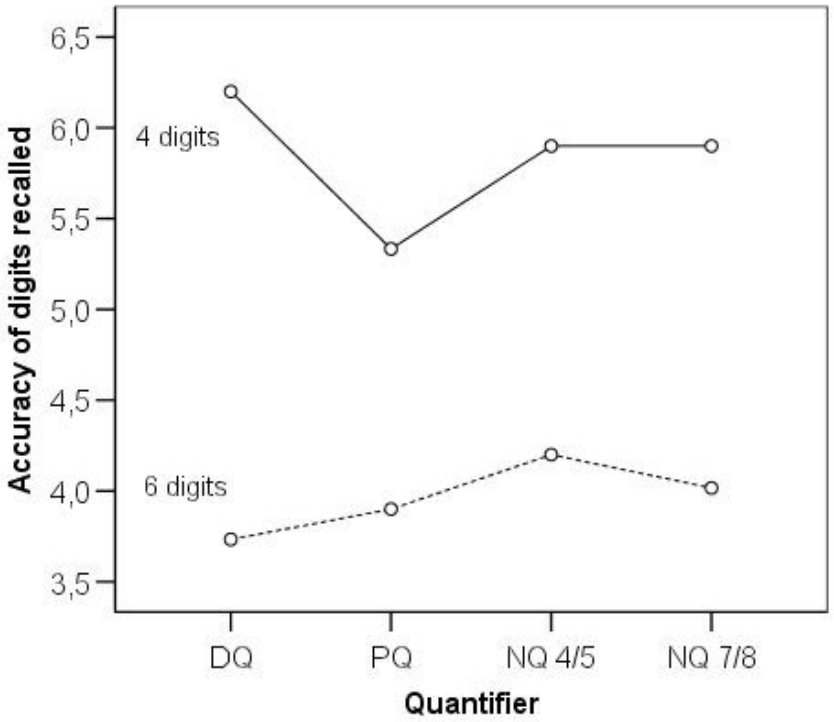
In 4-digit condition all quantifiers were performed worse.

Memory task: recall accuracy



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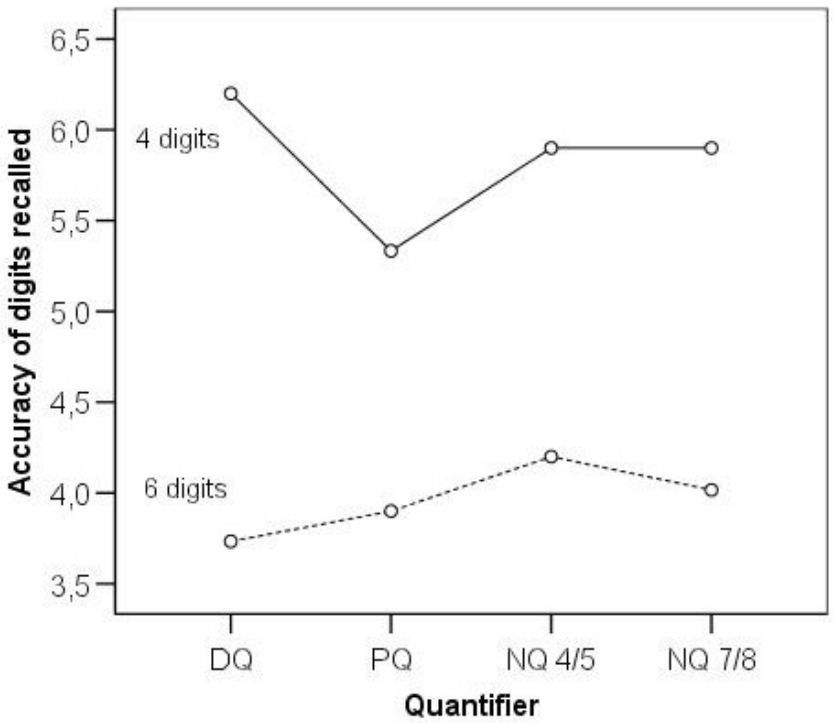

- In 4-digit with PQ: the worst;

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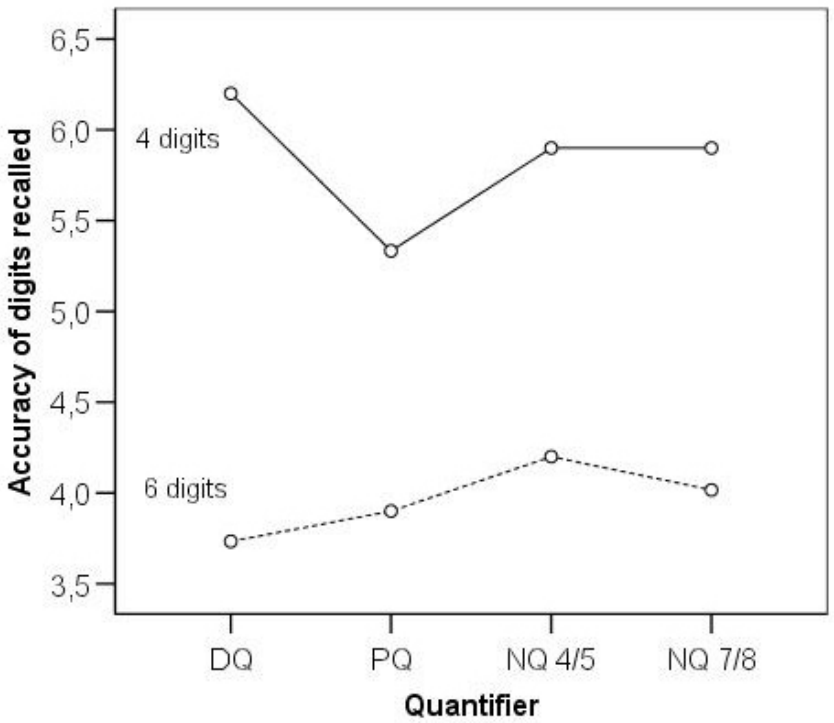

- In 4-digit with PQ: the worst;
- In 6-digit: no differences.

Outline

Summary

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- Discrepancy under two memory load conditions:
  - The real differences occurred only in 4-digit condition.
  - Holding six elements in memory was probably too difficult.
  - Trade-off between processing and storage.

Proportional quantifiers

- 4-digit strings accompanying this class were recalled worst.
- But no differences in 6-digit condition:
  - RT decreased: subjects ignored recalling.
- WM engagement PQ processing is qualitatively different.

Numerical quantifiers

Hypothesis

The number of states is a good predictor of cognitive load.

Difference between numerical quantifiers of low and high ranks.

Thank you!