STM/WM

Weighting: 1/17

Todd, J. J., & Marois, R. (2004). Capacity limit of visual short-term memory in human posterior parietal cortex. *Nature*, *428*(6984), 751–754.

# Agenda

* What is STM/WM?
* The article: Capacity limit of visual short-term memory in human posterior parietal cortex
* Motivation and hypothesis
* Method
* Results
* Authors’ conclusion
* Criticism
* Greater perspective

# What is STM/WM?

## Working memory

Memory held briefly in the mind that enables completion of a particular task (e.g., efficiently searching a room for a lost object).

## Short-term memory

Information held briefly in consciousness which may be easily lost (by interference or degrading) if not rehearsed and/or transferred to long-term memory.

## Visual short-term memory

Short-term memory specifically dedicated to visual scene representation yet distinct from iconic memory. Capacity: Three to four items.

# The article: Capacity limit of visual short-term memory in human posterior parietal cortex

“With the use of functional magnetic resonance imaging, we show here that this capacity limit [of VSTM] is neurally reflected in one node of this network: activity in the posterior parietal cortex is tightly correlated with the limited amount of scene information that can be stored in VSTM. These results suggest that the posterior parietal cortex is a key neural locus of our impoverished mental representation of the visual world.” (p. 751)

## Hypothesis

VSTM capacity has a neural base

his base is IPS/IOS (intraparietal and intraoccipital sulci)

* IPS/IOS activity reflects VSTM capacity limits and NOT iconic memory

## Experiment 1

### Method (Figure 1)

* *N* = 17 in **fMRI scanners**
* **dual task paradigm:** The phonological loop is occupied by remembering digits (auditory stimulus)
* 1-8 colored discs are presented (memory set) for 150 ms (increasing to 450 ms did not increase *K*)
* 1200 ms retention period to minimize effect of iconic memory and reduce decay
* Probe: determine if probe was same color and position as memory set
* Digit probe

### Results

* Performance in the verbal task was high (92-94 % across set sizes) implying its independence from VSTM
* Accuracy in the VSTM task declined with increased set size

#### Figure 2:

* The number of objects encoded at each set size, estimated with Cowan’s K formula increased up to set size 3 or 4, and levelled off thereafter
* **VSTM capacity is about 3 or 4 items, consistent with previous studies**
* **The task used examines VSTM capacity rather than encoding limits:** Tripling the sample presentation time (to 450 ms) did not affect the *K* function (separate experiment, n = 16, P = 0.28)

#### Areas which are relevant to VSTM capacity should show a BOLD response mirroring the K function (capacity graph): Figure 2 and 3a

To isolate such regions, a voxel-based multiple regression analysis with K-weighted set size coefficients was performed.

* The IOS/IPS fit these criteria.
* Figure 2: both the *K* function and the BOLD response in the VSTM task increase with set size but level off at about 3
* Figure 3a: Time-course analysis confirmed strong correlation between objects encoded and BOLD response
* The BOLD response is not related to task difficulty but to VSTM capacity as the response is the same for set size above 4
  + A different test attempting to overload the WM of 4 participants showed an increase in signal amplitude because of summation of overlapping individual BOLD responses (the levelling off of the BOLD response is not due to saturation – *more blood/oxygen will fit*)
  + The same experiment with white bars in different orientations also produced IPS/IOS involvement (highly correlated with *K* function) -> they are involved in all matters of VSTM regardless of stimulus type

## Experiment 2: Perceptual or iconic representations?

Could IPS/IOS activity reflect the perceptual or iconic representation of the number of objects in the scene instead of the number of objects stored in VSTM?

### Method

* Identical to first experiment except that the phonological part was removed, and participants only needed to worry about the center position to produce equal and minimal VSTM demands across set sizes

### Results

* Performance was near ceiling in all set sizes (96-98%)
* The response was attenuated and there was no set size effect
* **Thus, the IPS/IOS is insensitive to the perceptual load of the visual scene.**

## Experiment 3: Encoding, maintenance and retrieval phases

If the IPS/IOS is involved in VSTM storage, it should be engaged during maintenance, and not just at encoding or retrieval. Because of the short retention interval used in the VSTM experiment, the IPS/IOS response in each of these phases could not be distinguished. We therefore performed an additional VSTM load experiment with a sufficiently long retention interval (9,200 ms) to dissociate activity related to encoding, maintenance and retrieval.

### Method

* Similar to first experiment, but included only 2 different set sizes (1 and 3)
* Maintenance/retention phase increased from 1200 to 9200 ms

### Results (Figure 4)

* IPS/IOS was activated at the larger set size during encoding and maintenance
* No difference during retrieval
* **The IPS/IOS is sensitive to WM load mainly during encoding and maintenance rather than retrieval**

## Experiment 4: Is IPS/IOS still involved when only object identity is required?

An additional experiment investigated whether the IPS/IOS would still be involved in VSTM when only a judgement of object identity is required. This task was identical to the first experiment except that the location information was rendered task-irrelevant by always presenting the probe disc at fixation. Activation in the IPS/IOS ROI was still load-dependent (F5,15 = 3.72, P = 0.05, n = 4) and was correlated with the K function (r = 0.70, t3 = 3.67, P = 0.05), indicating that the IPS/IOS might be involved in several forms of VSTM storage.

### Method

* Experiment identical to first experiment except the location information was rendered task irrelevant by always presenting probe at fixation

### Results

* Activation in the IPS/IOS was still load dependent and correlated with *K* function
* IPS/IOS is likely involved in several forms of VSTM storage

## Experiment 5: Do other brain regions track VSTM storage capacity?

### Method

* The statistical parametrics threshold was relaxed 10-fold in the data from the first experiment

### Results (Figure 3b and 3c and 4)

* Two areas emerged
  + ACC (anterior cingulate cortex)
  + An area in VO (ventral occipital cortex) corresponding to V4 (an extrastriate area involved in colour processing)
* Activity in these areas was different from IPS/IOS activity on all parameters:
  + Peak BOLD response in the two areas had a linear function (meaning activity increased above set size of 4)
  + Neither showed sustained response during maintenance in the extended VSTM retention experiment (Figure 4b and 4c) – what we call experiment 3
  + VO and ACC VSTM-related activity may be largely accounted for by perceptual and/or response components of the task (button pressing)
    - This is especially true for VO which showed a strong set size effect under iconic memory conditions (contrary to IPS/IOS). Indicating that activity in VO might be driven by perceptual load rather than how much can be held in VSTM about the scene.

## Author’s conclusion

Based on the BOLD responses, authors conclude that IPS/IOS is involved in VSTM capacity limit.

Further, authors conclude that AC and VO are NOT involved in VSTM capacity limit.

Although our results provide little evidence that the capacity limit of VSTM storage is a distributed property of the working memory network, they do not exclude the possibility of additional neural contributions below the level of fMRI detection, nor are they inconsistent with the established role of the frontal/ prefrontal cortex in working memory. Whereas the posterior parietal cortex might act as a capacity-limited store for the representation of the visual scene, the frontal/prefrontal cortex might be necessary for the consolidation and/or maintenance of this store, especially during extended retention intervals. Whatever the contributions of other brain regions might be, this series of experiments points to the posterior parietal cortex as a key neural locus of our impoverished mental representation of the visual world.

## Criticism

* Subject age not stated (fairly small sample *N* = 17) – are these brains fully developed? Would the regions be different or serve different functions in a different sample?
* Sub-areas of IPS have previously been associated with visual control of grasping, pointing and hand movements – are we looking at another button pressing area? A hand-eye coordination area?
* It’s all correlations

## Perspective

* Similarities in paradigm: Sternberg
* TVA: studies VSTM *encoding* speed and capacity
* Baddeleys WM model ––> other memory models
* Distribution of functions: Cowans model of working memory (VSTM is distributed somewhat akin to working memory in Cowan’s model)
* Association cortices: integration info from various modalities with higher functions (the brain is multimodal )
* Ventral stream (what) and dorsal stream (where)
* Experiment where Ps had to determine if 1 of 2 shown gratings (lines) held in STM were rotated left or right: V1-4 activity predicted which grating was being held in memory
* Brown-Peterson task
  + Trigram of letters -> interference task (counting backwards in threes) -> recall trigram
  + Proactive interference: performance decreases following each trail, but when task is changed, performance increases back to baseline
* Specific neurons in dlPFC are localized to parts of visual field, but only when keeping information from it in mind, not when viewing it.