# Aging and synaesthesia provide a window into the functions of sensory and higher cortical areas in working memory

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## Introduction

The sensory recruitment model envisages visual working memory (VWM) as an emergent property that is encoded and maintained in sensory (visual) regions and facilitated by top-down control from prefrontal cortex (PFC) (Serences et al., 2009). The model implies that synaesthesia, where sensory-perceptual functions are enhanced (Figure 2), entails an efficient VWM-network with reduced activity in visual areas and PFC; while in old age, when sensory-perceptual functions decline, the effect will be reversed. We tested this model using a novel between-group-design with young grapheme-colour synaesthetes, young and older controls.

We employed two working memory tasks: 1) a delayed pair-associative (DPA) retrieval task, and 2) a delayed matching-to-sample (DMS) task, using achromatic fractal images (Figure 1).

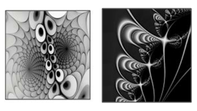

**Figure 1.** Example of experimental stimuli

**HYPOTHESIS**

The synaesthetes' enhanced neural sensitivity in posterior visual regions was expected to facilitate stimulus-representations during VWM, showing reduced activity in occipital-temporal regions and lower top-down activity from PFC compared to the other two groups.


**Figure 2.** Perceptual experiences of grapheme-colour synaesthetes

## Methods

**PARTICIPANTS**

19 young adults (8 female; M = 24.32)
19 young grapheme-colour synaesthetes (15 female; M = 23.00)
19 older adults (11 female; M = 66.21)

**Self-paced learning (pre-scanning session)**

- For the DPA-task (Figure 3), participants learned 8 fractal pair-associates to 87% correct performance criterion on a computer.
- For the DMS-task (Figure 4), participants engaged in a simple recognition test to increase picture familiarity.

**DPA and DMS tasks during fMRI**

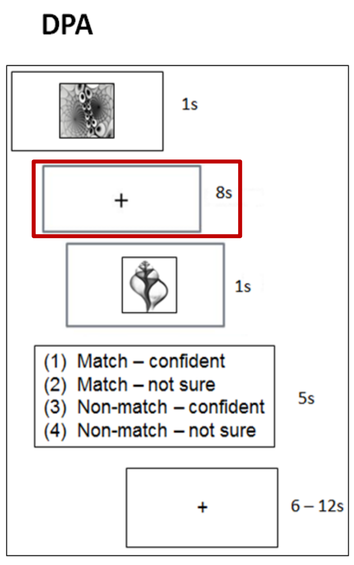


**Figure 3. Delayed Pair-Associative (DPA) Retrieval example trial**

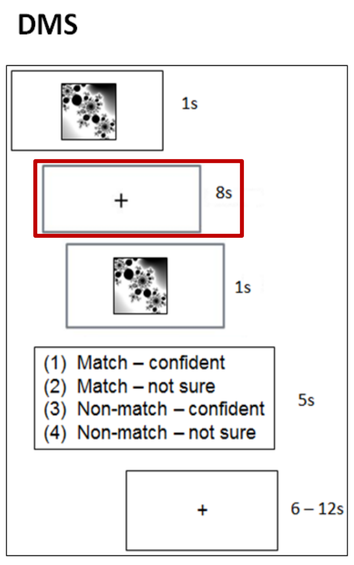


**Figure 4. Delayed Match-To-Sample (DMS) example trial**

**fMRI protocol & analyses**

- We used an event-related design.
- Hits & Correct rejections were analysed for both tasks using the GLM. Events were convolved with a canonical HDR function. The delay-period was modelled to start 3 seconds after delay-onset and lasted for 5 seconds until the end of the delay-period. This was done to explain a largely unique source of variance pertaining to delay-period activity (Rissman et al., 2004).
- Contrast images were computed for *DPA>Baseline* and *DMS>Baseline*. Group effects were inclusively masked with the average task effects across DPA/DMS and a suprathreshold of $p < 0.001$ (uncorrected), k= 5 voxels was applied.
- Percent signal change was extracted from brain regions showing a significant group effect for post-hoc analyses.

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## Results

**Synaesthetes show reduced activation in visual areas during visual working memory (averaged across DPA and DMS-tasks)**

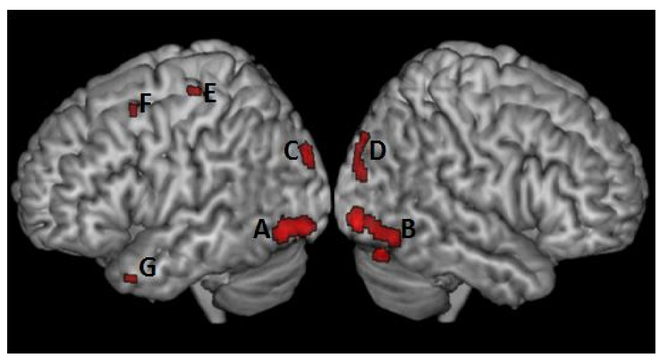
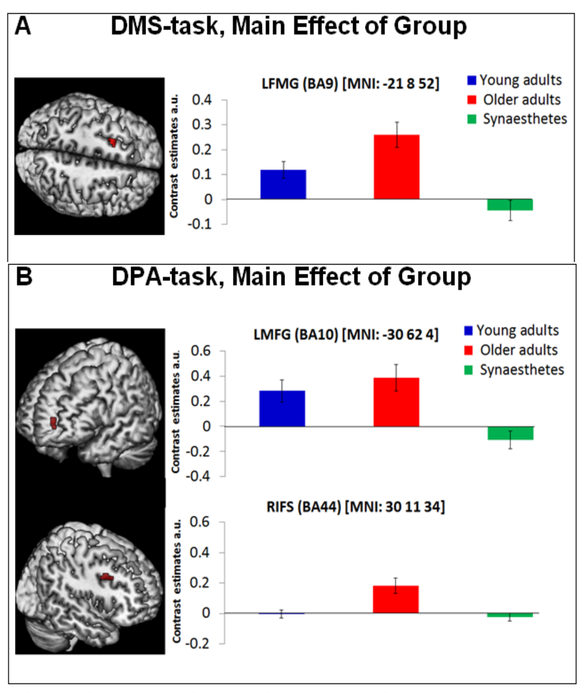



**Figure 5.** Top: Group differences are shown in the bilateral inferior temporal gyrus (**A, B**), bilateral superior occipital gyrus (**C, D**), the left precentral gyrus (BA6; **E**), left middle frontal gyrus (BA9; **F**), and the left medial temporal pole (BA38; **G**). Bottom: Peristimulus time histograms (PSTH). Trial-averaged responses for all groups were rescaled to the percent signal change of each mean cluster activity relative to cue-onset. Error bars represent the standard error of the mean. Reduced signal strength was found in synaesthetes relative to young and older adults during the delay period in regions **A-G**. The bars below each x-axis indicate the timing of cue and target stimulus presentation (white bar) and the delay period (black bar). A grey-scaled gradient bar above each x-axis depicts the expected peak of the BOLD response for WM-related activity, assuming a 4-6 second peak latency of the hemodynamic response. LIO = Left Inferior Occipital Gyrus, RIO = Right Inferior Occipital Gyrus, LSO = Left Superior Occipital Gyrus, RSO = Right Superior Occipital Gyrus, LPcG = Left Precentral Gyrus, LMF = Left Middle Frontal Gyrus, LMTP = Left Medial Temporal Pole. Regions of each PSTH are denoted with their cluster peak in MNI.

**Synaesthetes show reduced activation in prefrontal cortex during visual working memory**




**Response Accuracy**

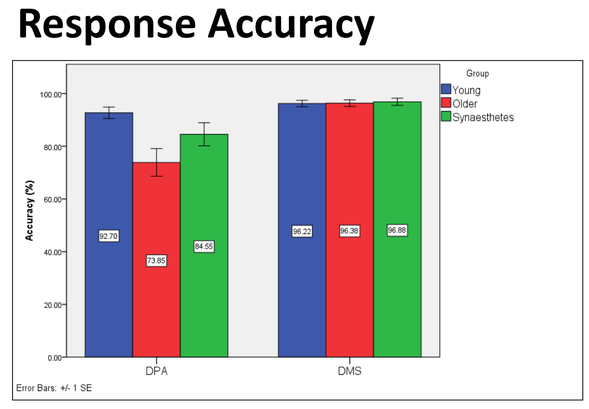



**Figure 7.** Behavioural responses during the DPA and DMS-task

**Figure 6.** The DMS-task yielded a main effect of group in the Left Middle Frontal Gyrus (BA9) (**A, left**). The DPA-task yielded a main effect of group in the Left Middle Frontal Gyrus (BA10) and the Right Inferior Frontal Gyrus (BA44; **B, left)**. Contrast estimates are reported for each mean cluster activity of DMS and DPA (**A and B, right**). Error bars represent the standard error of the mean. Synaesthetes showed significantly lower activity relative to older adults in all frontal regions. Synaesthetes also exhibited significantly lower activity than young adults in the Left Middle Frontal regions of the DMS and DPA task (**A and B, top**). LMFG = Left Middle Frontal Gyrus, RIFS = Right Inferior Frontal Sulcus, a.u. = arbitrary units.

## Conclusions

Our results revealed prefrontal and occipital-temporal contributions to VWM that reflected the differences in visual perception between synaesthetes, young and older adults. Synaesthetes showed reduced activity in sensory and higher level cortical regions relative to young and older adults, suggesting that enhanced sensory-perceptual functions (as in synaesthesia) facilitate top-down control from PFC during higher-level VWM processes.

## References

Serences JT, Ester EF, Vogel EK, Awh E (2009) Stimulus-Specific Delay Activity in Human Primary Visual Cortex. Psychol Sci 20:207-214.
Rissman J, Gazzaley A, D'Esposito M (2004) Measuring functional connectivity during distinct stages of a cognitive task. Neuroimage 23:752-763.

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