Effect of cross-modality on the precision of working memory representations and fMRI activity patterns

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Psychophysics

INTRODUCTION

- There is an ongoing debate on working memory resources:
1. Does WM contain separate and independent memory storages for visual and auditory information (Baddeley, 2010) or are resources domain-general (Cowan, 2011)
2. Is memory based on discrete slots (Zhang & Luck, 2008) or continuous resources (Bays & Husain, 2008)
- Precision of representations sets the limit for both visual (Bays & Husain, 2008; Salmela & Saarinen, 2013; Wilken & Ma, 2004) and auditory (Kumar et al., 2013) memory performance, suggesting resource sharing
- We tested whether memory resources are shared across representations in different sensory modalities

METHODS

- Sinewave gratings presented simultaneously with sinewave tones (Fig.1)
- Visual features: spatial frequency and orientation
- Auditory features: pitch and tone duration
- Memory precision => delayed discrimination threshold
- Two-interval 2-1 staircase => 70.7%
- Each feature separately and all possible feature combinations
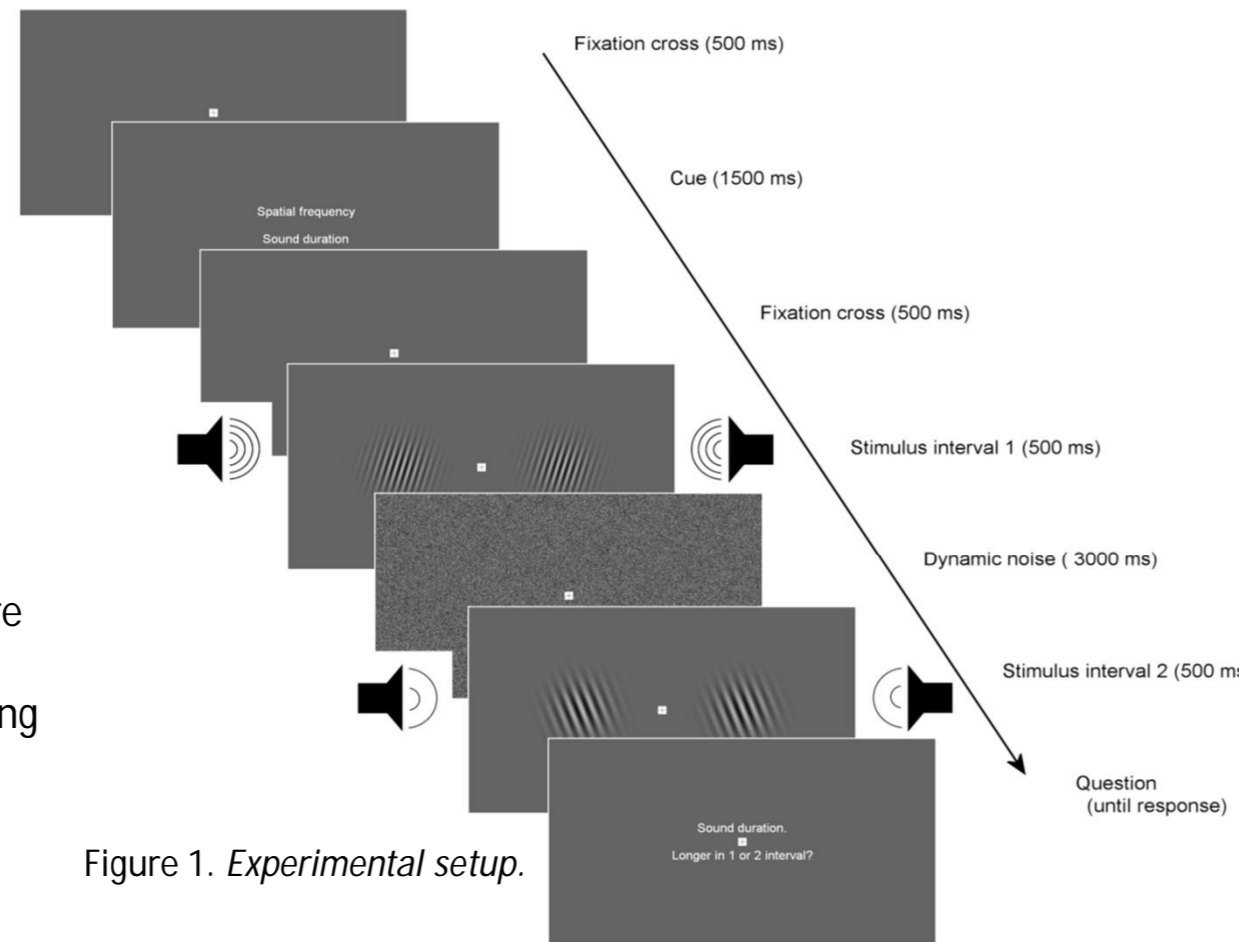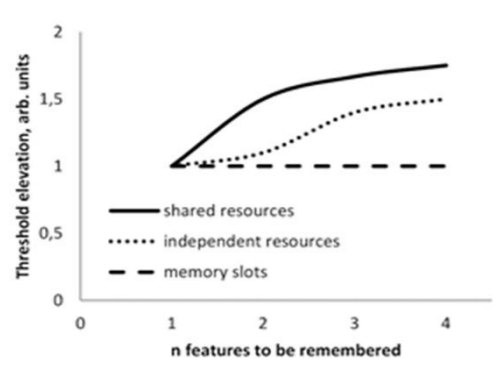- Only the memory load was varied while keeping the stimuli similar across conditions

Figure 1. *Experimental setup.*

RESULTS - Precision

- Possible outcomes

- Memory precision for a single feature was close to perceptual threshold (Fig. 2)
- Precision collapsed as the number of features to-be-remembered was increased above one (Fig. 2; p<.01)
- Resource sharing function fits the data well (Table 1):

$$Th = \left(\frac{1}{n}\right) Th_{n=1} + \left(1 - \frac{1}{n}\right) As$$

(n = number of stored features; $Th_{n=1}$ = threshold with one item; As = constant asymptote)

Table 1. Constant parameter and R^2 of the fitted functions.

	Average	SF	pitch	OR	dur
As	3.02	0.62 c/deg	50.2 Hz	21.8 deg	98.7 ms
R^2	.98	.96	.95	.98	.83

Figure 2. *Discrimination threshold as a function of memory load. (percision = 1/threshold)*

RESULTS – Cross-modality

- Possible outcomes

- No cross-modal benefit in any condition.
- Cross-modal thresholds were different than intra-modal thresholds only in 1/8 conditions (orientation & pitch/duration)
- Simultaneously storing one visual and one auditory feature had an equal effect on memory precision as simultaneously storing two visual or two auditory features.
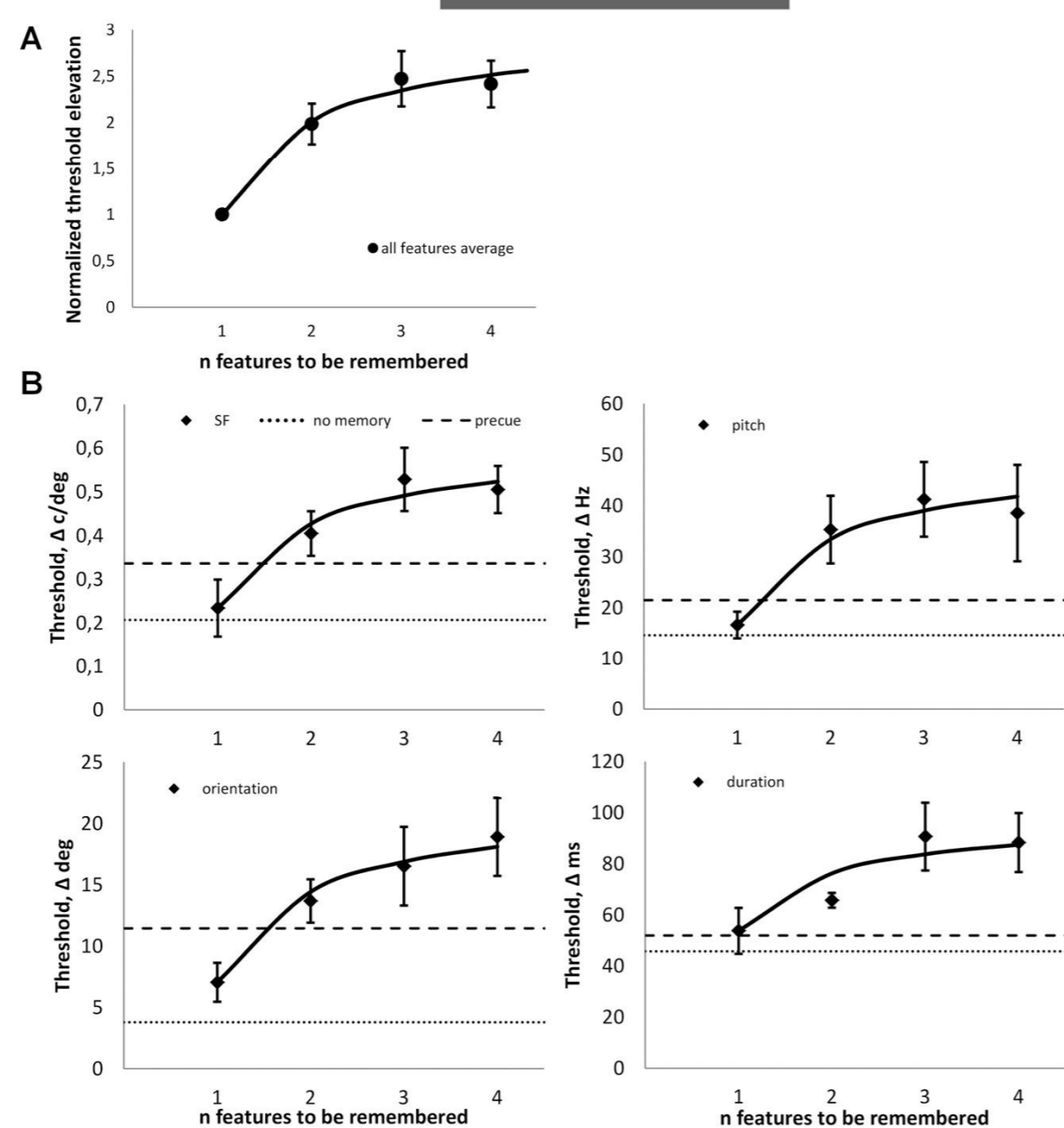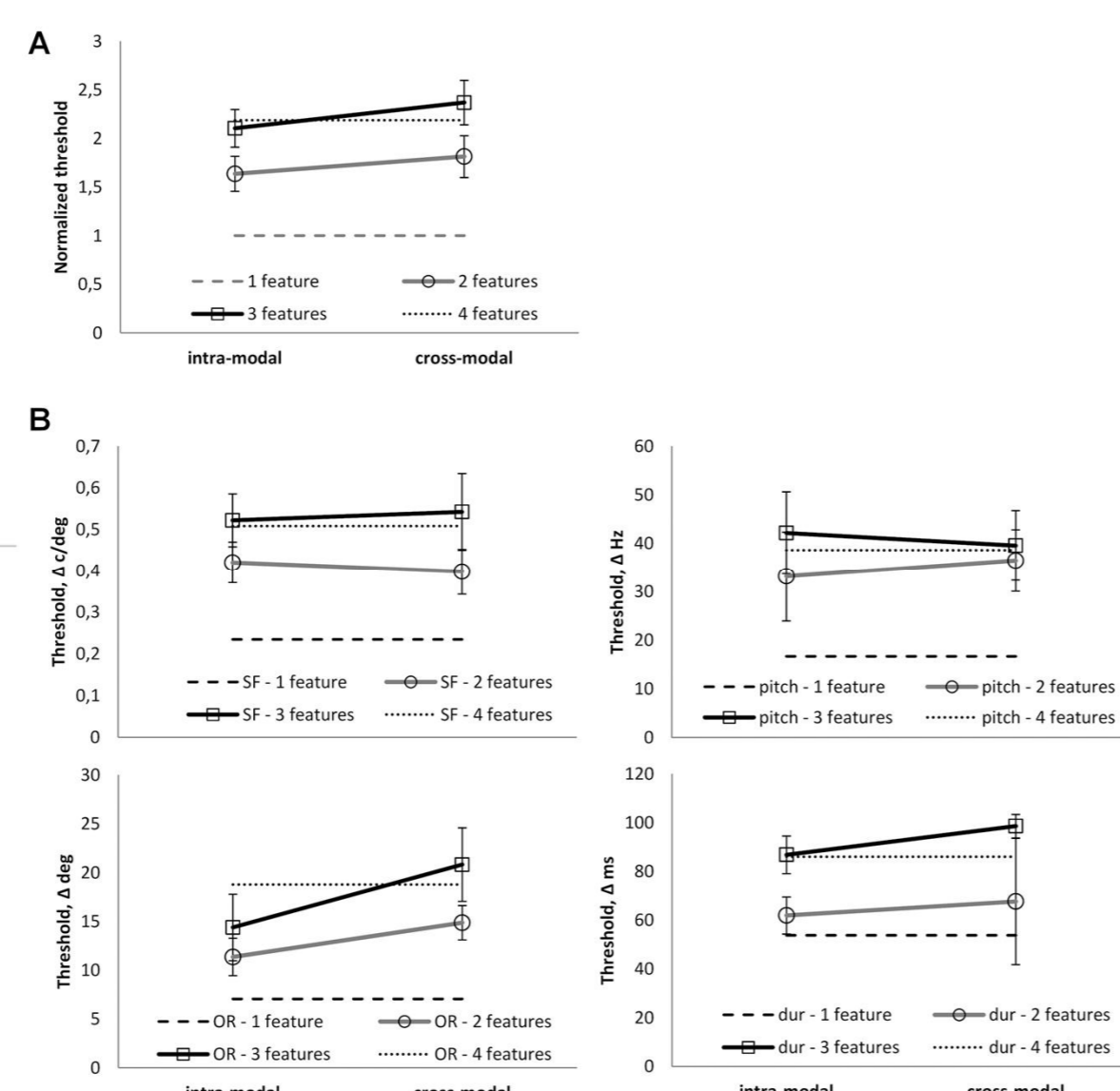

Figure 3. *Thresholds in intra-modal and cross-modal conditions.*

CONCLUSIONS

- Working memory performance is limited by the precision of the stored representations, not by discrete memory slots
- Working memory can be described as a common resource pool shared between sensory modalities

fMRI

INTRODUCTION

- No sustained activity in the visual cortex during memory maintenance, but activity patterns predict memory performance (Harrison & Tong, 2009)
- Pattern classification accuracy decreases as a function of memory load and the decrease correlates inversely with memory precision (Emrich et al. 2013)
- We tested whether BOLD-responses and activity patterns in sensory cortices differ in intra-modal and cross-modal conditions.
- We measured the effect of attention, dual-tasking & cross-modality on
1. time-course of BOLD signal
2. event related responses to stimulus encoding and memory maintenance
3. multi-voxel activity patterns during encoding and memory maintenance

METHODS

- Two-interval setup (Fig.4)
- Similar to psychophysics, but:
  -retention time 7000 ms, no noise
  -auditory features: average pitch and frequency range of tone stream ("musical rain"): 14 tones, 40 ms, breaks 10 ms
  -discrimination task, constant difference
  - 4 diff stimuli in each category
  -five conditions, memorize:
1. pitch (one auditory feature)
2. orientation (one visual feature)
3. pitch and orientation (cross-modal)
4. orientation and spatial freq. (visual intra-modal)
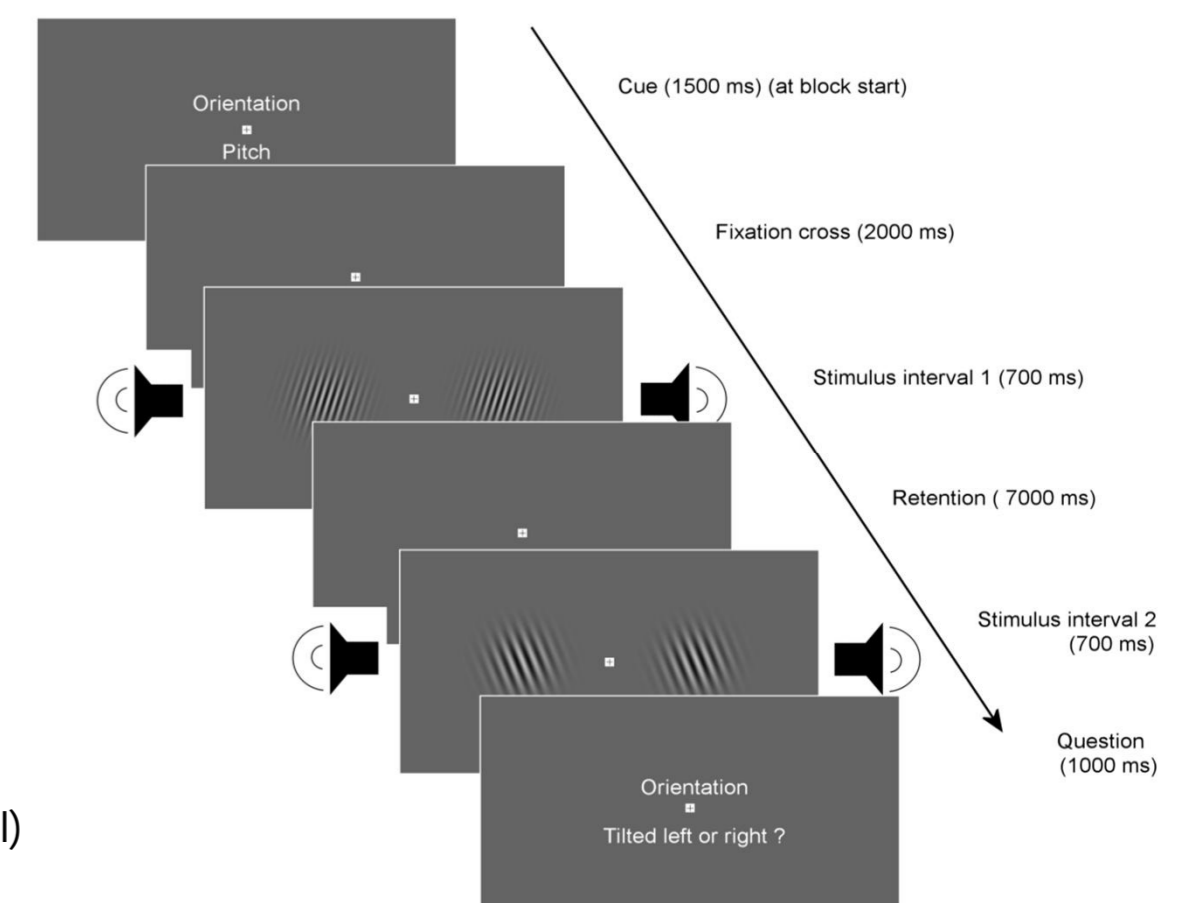5. pitch and freq. range (auditory intra-modal)

Figure 4. *Experimental setup.*

RESULTS
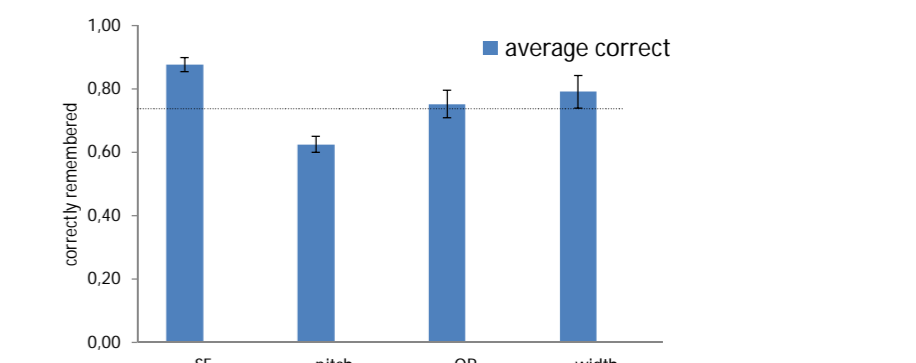
- Behavioral performance, ~75% correct (Fig. 5)

Voxel-wise analysis
- Functional localizer activated clear clusters in auditory and visual cortex (Fig. 6)
  -visual localizer = contrast-reversing checkerboard
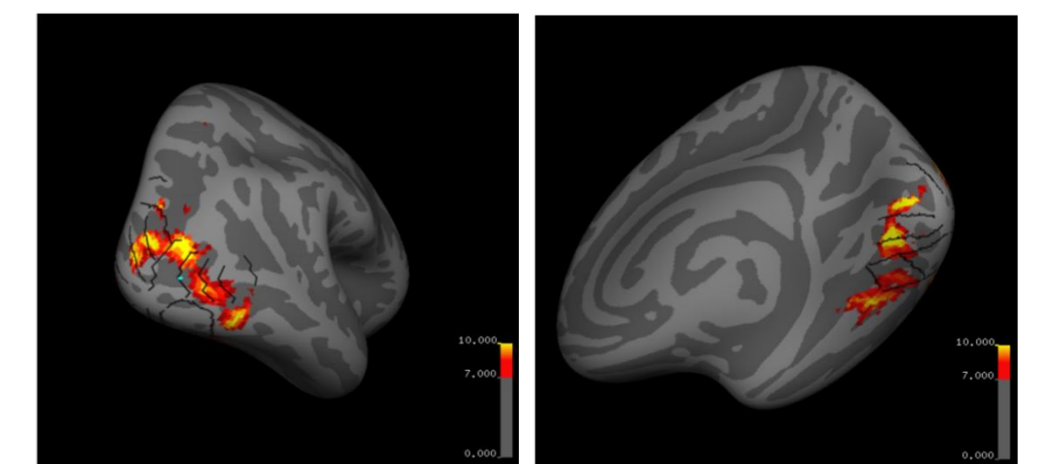 -auditory localizer = 2 s stream of random tones

Figure 5. *Average of correct answers.*

- Time course of BOLD-signal: overall increase due to dual-tasking and attention (Fig. 7)

Figure 6. *Functional localizers. Average activation across subjects. p<.05 (FWE)*
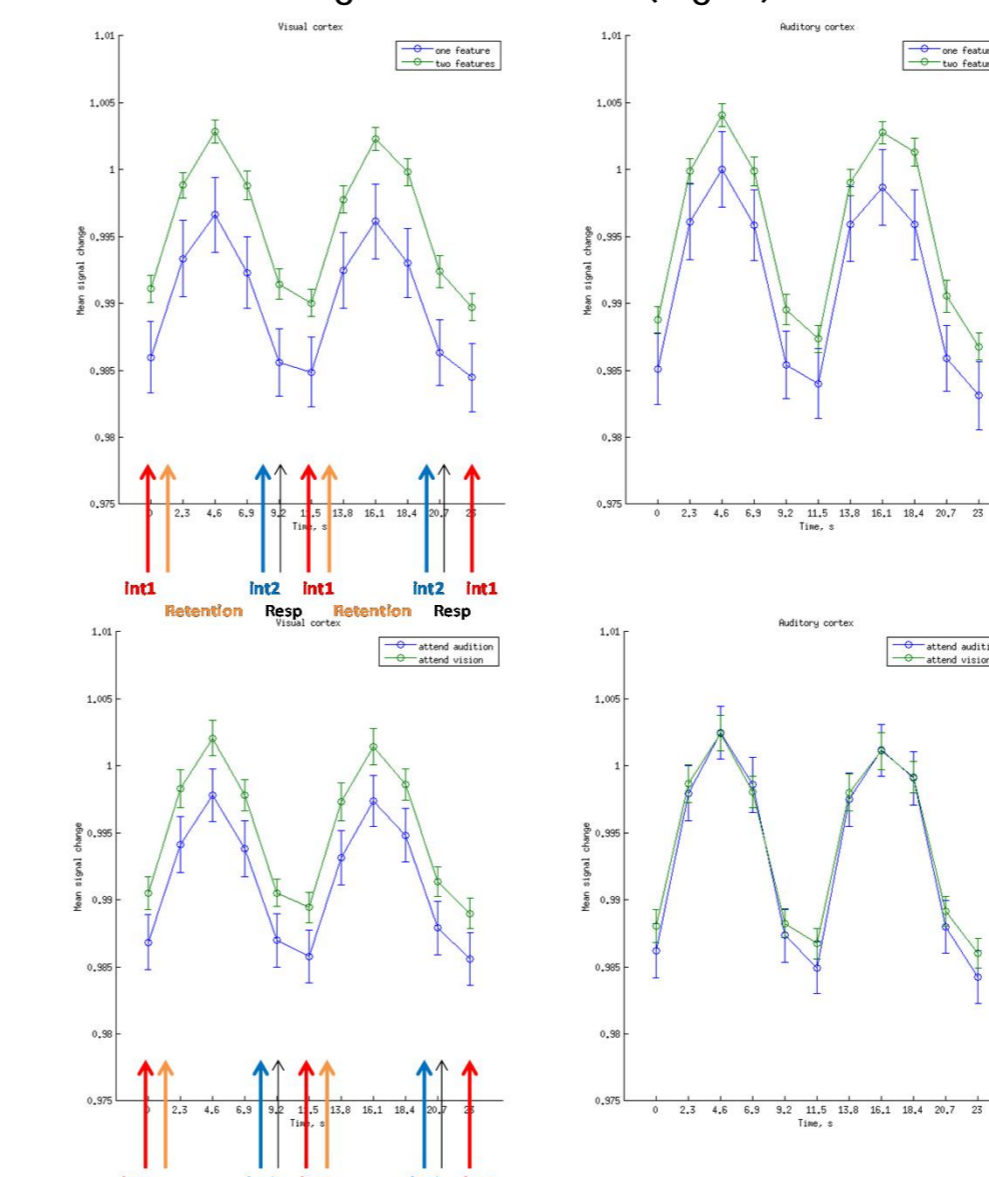

Figure 7. *Time-course of BOLD-signal*

- No activity during memory maintenance (Fig. 8)
- Responses to stimuli increased due to attention, dual-tasking and cross-modality (Fig. 8)
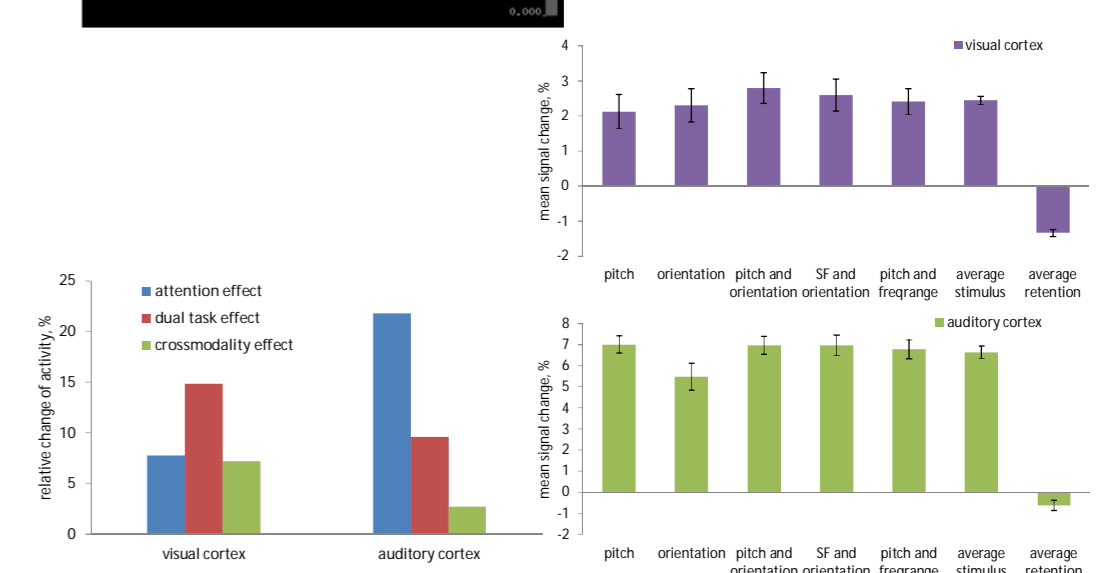
Multivariate pattern analysis
- Not yet completed
- Searchlight analysis (circular, radius 3 voxels, volume ~100 voxels) will be conducted to find voxel clusters that contain most relevant information (Kriegeskorte et al., 2006)
- Representational similarity Analysis (Kriegeskorte et al., 2008) will be used to classify different conditions (Fig. 9)
- Within the searchlight, we will calculate correlation of the activity patterns to representational matrices corresponding to: feature type, feature value, modality, task type, and all combinations of these
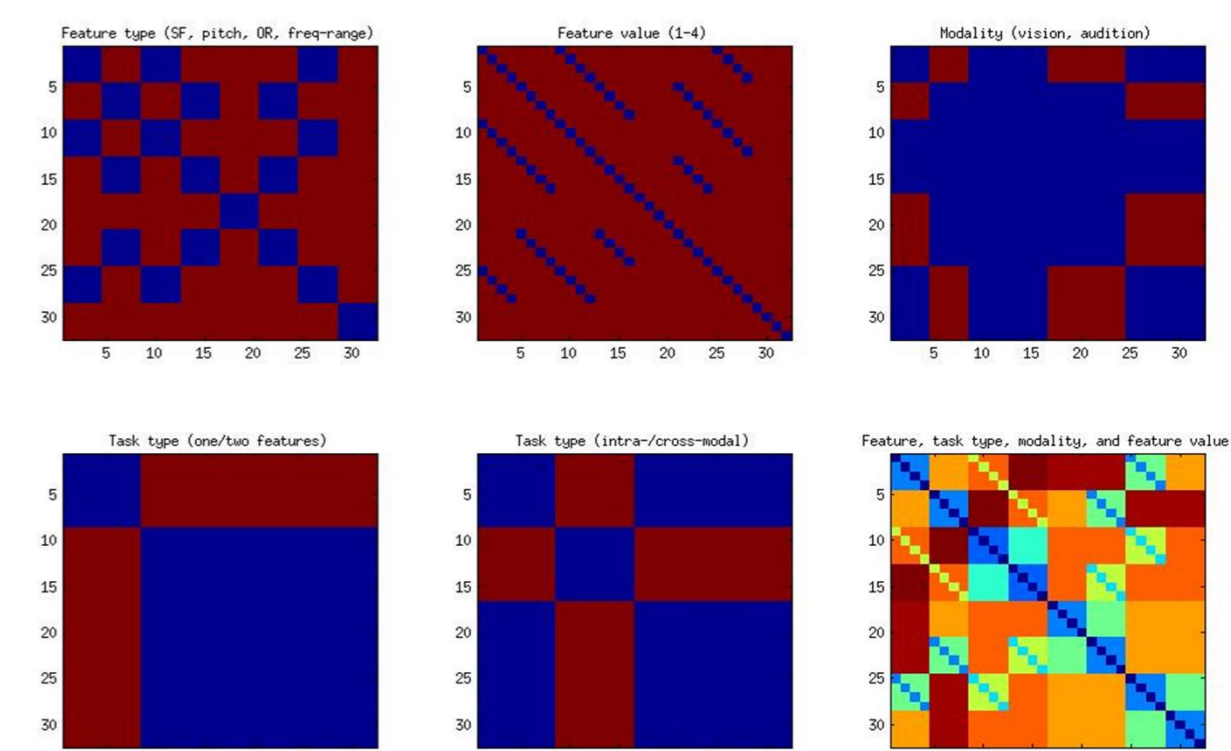

Figure 8. *Event-related responses and the effect of attention, dual-tasking and cross-modality.*

Figure 9. *Classification of experimental conditions with representational matrices.*

References

Baddeley, A. D. (2010). Working memory. Curr Biol, 20(4), R136-140.

Bays, P. M., & Husain, M. (2008). Dynamic shifts of limited working memory resources in human vision. Science, 321(5890), 851-854.

Cowan, N. (2011). The focus of attention as observed in visual working memory tasks: making sense of competing claims. Neuropsychologia, 49(6), 1401-1406.

Kumar, S., Joseph, S., Pearson, B., Teki, S., Fox, Z. V., Griffiths, T. D., & Husain, M. (2013). Resource allocation and prioritization in auditory working memory. Cogn Neurosci, 4(1), 12-20.

Emrich, S. M., Riggall, A. C., Larocque, J. J., & Postle, B. R. (2013). Distributed patterns of activity in sensory cortex reflect the precision of multiple items maintained in visual short-term memory. J Neurosci, 33(15), 6516-6523.

Harrison, S. A., & Tong, F. (2009). Decoding reveals the contents of visual working memory in early visual areas. Nature,

458(7238), 632-635.

Kriegeskorte, N., Goebel, R., & Bandettini, P. (2006). Information-based functional brain mapping. Proc Natl Acad Sci U S A 103(10): 3863-3868.

Kriegeskorte, N., Mur,M., & Bandettini, P.(2008). Representational similarity analysis - connecting the branches of systems neuroscience. Front Syst Neurosci 2: 4.

Salmela, V. R., & Saarinen, J. (2013). Detection of small orientation changes and the precision of visual working memory. Vision Res, 76, 17-24.

Wilken, P., & Ma, W. J. (2004). A detection theory account of change detection. J Vis, 4(12), 1120-1135.

Zhang, W., & Luck, S. J. (2008). Discrete fixed-resolution representations in visual working memory. Nature, 453(7192), 233-235.