Neural differentiation at encoding predicts subsequent source memory performance in young and older adults

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Introduction

- Neural differentiation, the greater neural activity of a cortical region to a specific class of stimuli relative to other classes, declines with increasing age[1,2] This decrease in functional specialization with age is also referred to as Age-related Neural Dedifferentiation.
- It has been suggested that neural dedifferentiation is a crucial determinant of cognitive aging, following the prediction that the reduction of functional specialization leads to compromised fidelity of neural representations[3].
- However, prior research indicates that the decline of neural selectivity is not observed with all classes of perceptual stimuli. The effect can be observed when attending to images of scenes[4,5,6], and has also been reported within the FFA for face stimuli[5]. On the other hand, some studies did not find evidence for decreased neural selectivity for stimulus categories such as words[5] or familiar objects[4,6]
- Moreover, recent findings suggest that the relationship between memory performance and neural differentiation is age-invariant. That is, greater differentiation is associated with better memory performance, and this effect is not moderated by age[4].
- The research reported here examined age differences in neural differentiation while participants complete an encoding task involving words paired with face or scene stimuli. Importantly, the study assessed whether neural differentiation is a predictor of memory performance regardless of age.

Methods

Participants

- 24 younger adults (age range = 18 – 28 years, Mean = 22, SD = 3.24)
- 24 older adults (age range = 65 – 75 years, Mean = 70, SD = 3.46)
- Two study-test cycles inside scanner, additional data and findings from test phase reported elsewhere.

Study Phase

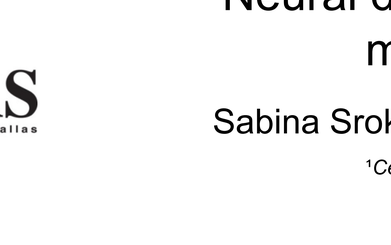
- 288 word–image pairs in 4 blocks
- Face trials:

"Imagine the person interacting with the object denoted by the word."

- Scene trials:

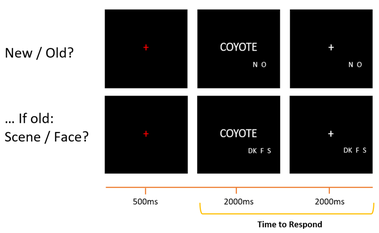
"Imagine the object denoted by the word interacting with the scene."

- Tasked to rate the vividness of the imagined scenario.



Test Phase

- 288 words from study + 96 New words
- First, participants indicated whether they remember seeing the word by responding: 'Old' or 'New'.
- For items endorsed as 'Old', participants retrieved the corresponding image category paired with the word at study.



MRI Methods:

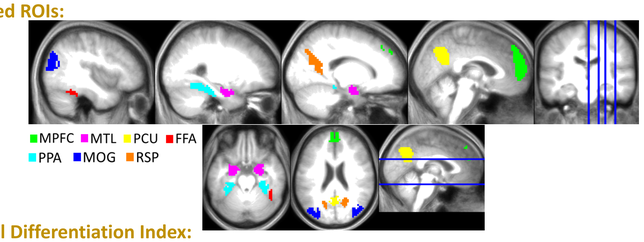
- T2*-weighted EPI (776 Study volumes, 992 Test volumes), 34 axial images/volume, 3mm thick, 1mm interslice gap, 3x3 mm in-plane, 80x80 matrix, TR = 2s, TE = 30ms
- fMRI data for the four study sessions were concatenated and subjected to a least-squares-all GLM to estimate the BOLD response for each individual trial. Events of interest were modeled as a 2s boxcar function convolved with a canonical HRF.

ROI Selection:

- The ROIs were empirically defined employing the 'leave-one-out' approach, in which a single pair of younger-older participants was iteratively left out from the GLM analysis. The ROIs are defined from group-level category contrasts (faces>scenes, scenes>faces) from the remaining participants. Thus, the data from the remaining subjects provide an unbiased set of ROIs for the left-out subject pair.

Age-related Neural Dedifferentiation

Defined ROIs:



Neural Differentiation Index:

- We computed a differentiation index for each ROI. The extracted mean BOLD activity per ROI was submitted into the following formula:

$$Differentiation\ Index = \frac{\mu_{pref} - \mu_{non\ pref}}{\sqrt{\frac{\sigma^2_{pref} + \sigma^2_{non\ pref}}{2}}}$$

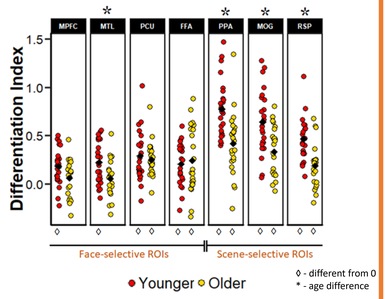
- The differentiation index for a given ROI is the difference in across-trial mean BOLD response for the ROI's preferred and non-preferred image class, divided by pooled standard deviation[5]. Higher score indicates greater neural selectivity.
- The following data are collapsed across subsequent memory. Identical results were observed when considering items which went on to receive a source correct response.
- Data entered into 2 (Age) x 7 (ROI) ANOVA, which resulted in a significant 2-way interaction, $p < .001$. Follow up analysis demonstrated reduced differentiation in MTL and all 3 scene ROIs with older age.

Face-selective ROIs:

Medial Prefrontal Cortex (**MPFC**), Medial Temporal Lobes (**MTL**), Precuneus (**PCU**), Fusiform Face Area (**FFA**)

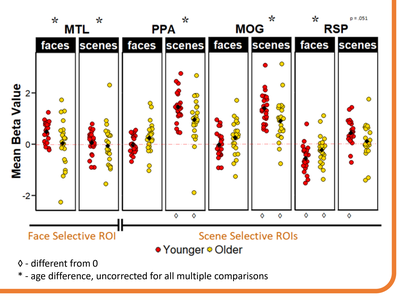
Scene-selective ROIs:

Parahippocampal Place Area (**PPA**), Middle Occipital Gyrus (**MOG**), Retrosplenial Cortex (**RSP**)

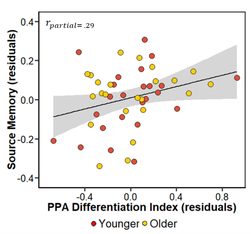


BOLD response to both classes of stimuli:

- To examine whether reduced differentiation is associated with neural attenuation or neural broadening, across-trial mean β-values for each image class in all ROIs were subjected to a 2 (Age) x 7 (ROI) x 2 (Image Class) ANOVA, which returned a significant 3-way interaction, $p = .007$, and a main effect of image class, $p < .001$
- Reduced BOLD response to scenes in PPA and MOG in older adults implies neural attenuation as the factor driving age-related neural dedifferentiation within these ROIs.



Differentiation and Source memory



- We have identified a positive relationship between PPA differentiation index and source memory when controlling for age, $r_{partial} = .29$, $p = .045$.
- Higher neural differentiation is associated with better source memory, and this relationship is age-invariant.

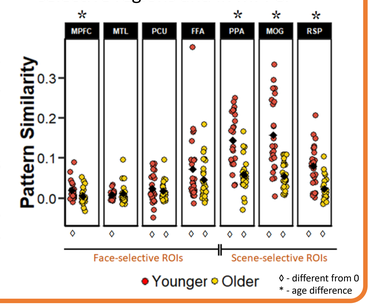
Multivoxel Pattern Similarity

- Multivoxel Pattern Similarity analysis was conducted complementary to the differentiation analysis. The underlying assumption behind this analysis is that the trials of the same stimulus class will result in similar neural patterns. This similarity is predicted to be higher with higher neural response of the ROI to its' preferred image class.

Computation of the Similarity Index:

- All computations were employed on single-trial β weights and conducted via Fisher z-transformed Pearson's correlation coefficients.
- The similarity metric was computed for each ROI as the difference between the within and between-category similarity measures. The within-category measure corresponded to the average across-voxel similarity between a given trial of the ROI's preferred image class (e.g. scenes for scene-selective ROIs) and all other trials of the same image class. The between-category measure was the average correlation between a given preferred image class trial and all trials of the other image class (e.g. objects for scene-selective ROIs).
- The similarity index for each participant was calculated by averaging their trial-wise within-between similarity measures.

The similarity indices were subjected to a 2 (Age group) x 7 (ROI) ANOVA. We observed a significant 2-way interaction, $p < .001$, which was driven by older adults showing lower similarity indices in the 3 scene-selective regions and in MPFC.



Conclusions

- Our findings are consistent with prior research which indicates that increasing age is associated with less distinctive neural representations. The Differentiation Index analysis revealed age-related neural dedifferentiation in all three of our scene-selective ROIs – PPA, MOG, and RSP[4,5,6].
- On the other hand, contrary to previous findings[5] we found no evidence for age-related neural dedifferentiation for faces within the FFA. We have two explanations: Unlike previous studies which employed passive viewing tasks, our encoding task required participants to generate a mental image of the person interacting with the object denoted by the paired word. Moreover, as prior research has provided little evidence for neural dedifferentiation for every-day objects and words, it is possible that age differences in neural differentiation are attenuated for highly familiar stimulus classes, such as faces.
- Furthermore, Multivoxel Pattern Similarity Analysis mirrored findings observed in the Differentiation Index analysis, that is, we observed reduced similarity indices for scenes in PPA, MOG, and RSP, but less evidence for age differences for faces. These results reveal that older adults show less similar neural patterns for scene trials, likely due to reduced precision and fidelity of neural representations.
- Lastly, our findings suggest that neural differentiation is a correlate of memory performance in both younger and older adults. Specifically, lower measures of neural differentiation are associated with poorer source memory regardless of age.

References

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