Age-related differences in visual statistical learning during face and scene working memory

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Abstract:

Visual information processing is not a simple reflection of the physical stimuli surrounding us, but rather emerges in interaction with our prior knowledge. One form of such interaction is visual statistical learning. Yet, the neural implementation and behavioral implications of visual statistical learning outside of long-term memory, remain largely unknown. Using face and scene-based working memory (WM) paradigms, we examined behavioral and neural correlates of visual statistical learning in WM and their age-related differences. We found that individuals of all ages exhibited faster response times and higher accuracy in face WM tasks compared to scene tasks. For visual images that were expected to form stronger associations between them, the young, but not older, adults showed significantly slower and less accurate responses. Strongly associated visual images were supported by increased frontoparietal activations in both age groups, suggesting a greater frontoparietal control demand on strongly associated visual information that may hamper WM performance.

Keywords: visual memory; statistical learning; face scene processing; aging

Introduction

In a glimpse of visual scenes and objects, humans can process several elements such as the overall gist, spatial layout, gross structural information, or a few objects embedded in the visual scenes. These elements activated at the initial encounter of visual information influence how viewers perceive, expect, and predict visual stimuli, which constitutes "top-down feedback" processing of visual information, whereas perceptual processes originating from the lower-level areas are referred to as "bottom-up feedforward" processing of visual information (Summerfield & de Lange, 2014). As such, it has been theorized that visual information processing is not a simple reflection of physical stimuli surrounding us, but rather emerges in interaction with our prior knowledge such as context, personal experience, and a probability of occurrences of visual stimuli.

One piece of supporting evidence for the top-down processing of visual information comes from the predictive coding literature (Friston, 2005; Rao & Ballard, 1999). Predictive coding theories state that neurons generate predictions higher up in the cortical hierarchy, and test these predictions against incoming sensory information in lower areas, producing an error signal if there is a mismatch between the prediction and current sensory information. The macaque ventral stream is organized by regionally specialized neural responses to view orientation and identify face stimuli. Using this hierarchical organization of regional specificity, studies have found that prediction error signals generated in a lower area actually map to the prediction of a higher area (Meyer & Olson, 2011; Schwiedrzik & Freiwald, 2017).

Successful memory of visual information has also been suggested to be acquired by feed-forward transmission of perceived visual information from the visual association cortex, such as lateral occipital cortex, fusiform gyrus, and inferior temporal cortex, to the medial temporal lobes (MTL), including the hippocampus and surrounding structures which have long been viewed as core brain structures supporting memory (Lavenex & Amaral, 2000). Emerging evidence, however, suggests that a dynamic interaction between attention, perception, and memory occurs to give rise to visual scene representations in memory (Kok & Turk-Browne, 2018; Sherman & Turk-Browne, 2020). Human fMRI studies have indicated an involvement of cortical and subcortical regions such as the frontoparietal cortices, visual association cortex, and the thalamus, in addition to the MTL. Yet, it remains largely unknown what precise role each brain region plays and how these brain regions interact in the service of visual scene memory. Studies have shown several mechanisms of interregional connection and their potential functions in the service of memory of visual information. A unifying whole-brain wise neurocognitive model that integrates precise contributions and interactions of each brain region, however, is still incomplete.

Here, in two behavioral experiments and one fMRI study, we examined behavioral performance and brain activation patterns during face and scene WM tasks in which visual stimuli were temporally linked to each other differentially, leading to predictive relationships between those strongly associated visual items. We hypothesized that strongly associated visual images would impair WM task performance that require a high level of control demand, especially in young adults, while the effect of visual statistical learning tapped by strong temporal associations would be lessened in older adults.

Results

Two behavioral experiments were performed in young adults (32 young adults in Behavioral Experiment 1 and 30 young adults in Behavioral Experiment 2); the only difference was the use of gray-scaled images in the first and colored images in the second. In both behavioral experiments, 2-back WM performance with strongly associated images (STRONG-PAIR) were slower and less accurate for both faces and scenes, compared to weakly associated images (WEAK-PAIR), in both experiments (**Figure 1A&B**).

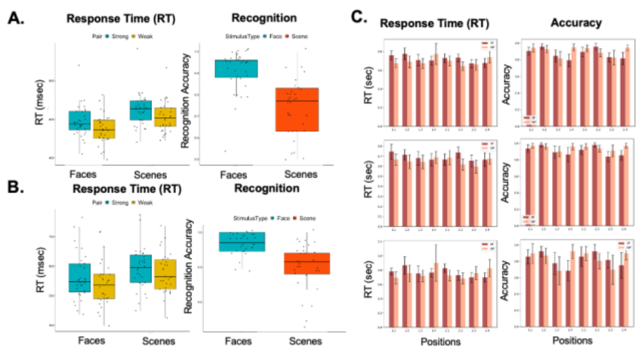

Figure 1: **A & B**: Behavioral Experiment 1(A) and 2 (B): Response time (RT) was faster with higher accuracy for faces than scenes (ps<0.001). Critically, RT was slower for STRONG-PAIR than WEAK-PAIR items (ps<0.001). **C**: Behavioral performance in fMRI study. RT and accuracy in all subjects (top row), young subjects only (middle row) and older subjects (bottom row). Data are shown by trial repeat positions. Collapsing the visual categories and pair positions in the tasks, young, but not older, subjects performed more slowly and less accurately for STRONG-PAIR than WEAK-PAIR items (ps<0.001).

In the fMRI experiment (27 young and 20 older adults), gray-scaled images were used. Images were presented in blocks of either faces or scenes. Some images were repeatedly followed by a predetermined image (STRONG-PAIR), some images are followed by different images in rotation (WEAK-PAIR), and the remaining images were randomly selected with no pre-specified temporal association (RANDOM). Across the age groups, response time (RT) was faster for faces than scenes (F=37.42, p<0.001) and accuracy was higher for faces than scenes in the 2-back task performance (F=15.18, p<0.001). Significant differences between STRONG-PAIR and WEAK-PAIR items, however, were seen only in young subjects (F=15.01, p<0.001), who have faster RTs for WEAK-PAIR items than STRONG-PAIR items (**Figure 1C**). Age-related differences were also observed in accuracy, with higher accuracy for WEAK-PAIR than STRONG-PAIR (F=9.74, p=0.004). Overall, young subjects responded faster and with higher accuracy than older adults (p<0.01). Thus, task performance during the fMRI study was similar to the performance observed in behavioral experiments, and older participants were slower in both face and scene WM tasks, compared to young adults.

Across the age groups, brain activation patterns differed between face and scene WM, showing the recruitment of more posterior brain regions involving the parahippocampal gyri and lateral occipital cortices bilaterally for scene WM, whereas fusiform gyri as well as wide spread regions including inferior parietal cortices bilaterally, ventromedial and dorsal medial frontal cortices, and precuneus were involved in face WM (uncorrected at a voxel level at p<0.001 and the whole-brain family-wise error correction at a cluster level at p<0.05 (two-sided))(**Figure 2A**). Greater activations in bilateral inferior and middle frontal gyri and right inferior parietal cortex were shown for STRONG-PAIR conditions, compared to WEAK-PAIR conditions collapsing faces and scenes, in which older subjects showed greater activations than young subjects in a subset of these regions (**Figure 2B**).

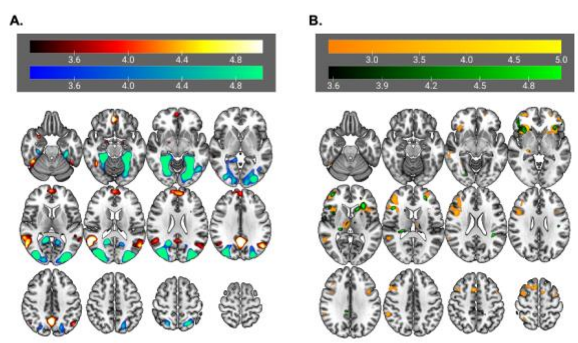

Figure 2: A. Brain activations during the face (warm-colored regions) and scene (cool-colored regions) WM tasks differ between stimulus type. **B.** Greater activations in bilateral inferior and middle frontal gyri and right inferior parietal cortex for STRONG-PAIR, compared to WEAK-PAIR conditions collapsing faces and scenes (warm-colored regions); greater activations in older than young subjects (cool-colored regions). FWE-corrected at the cluster level. Scale bars represent T values. Radiological convention.

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