

Novelty Discrimination of Configural Objects in the Perirhinal and Anterolateral Entorhinal Cortices Is Impacted by Aging

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The representational–hierarchical account of object processing characterizes the perirhinal cortex (PRC) as supporting conjunctive representations of object features, such that damage or age-related decline in the PRC impairs discrimination between complex object with overlapping features. In older adults, gray matter volume of the anterolateral entorhinal cortex (aLERC), a PRC-adjacent region, correlated with object discrimination based on configural (spatial) arrangements of features. However, this relationship has not yet been examined with functional activation or systematically investigated in aging. Importantly, object novelty discrimination can rely on changes at the feature-level (where all features are novel) or configural-level (where familiar features are rearranged in novel configurations), and the PRC/aLERC may differentially support these processes—differences that may become more pronounced with age-related neurodegeneration. However, distinguishing functional roles of the PRC/aLERC is complicated by inter-individual variability in their anatomical boundaries that may be exacerbated by aging. In the present fMRI study, we manually delineated the PRC/aLERC in a group of 43 younger (32 females) and 47 older adults (33 females) performing a configural object processing task with concurrent eye-tracking. In younger adults, gaze behavior and PRC activity distinguished both feature and configural novelty, whereas aLERC activity was sensitive to configural novelty. In contrast, age-related decline was most evident in the PRC's activation to configural novelty, and older adults showed no novelty-related differentiation in gaze behavior or aLERC function. These findings suggest the critical role of the aLERC in object processing and reveal age-related changes in the PRC/aLERC during novelty discrimination of complex objects.

Key words: anterolateral entorhinal cortex; cognitive aging; configural processing; eye-tracking; novelty discrimination; perirhinal cortex

Significance Statement

Recognizing whether an object is truly new—or just familiar parts in a new arrangement—relies on two brain regions: the perirhinal cortex (PRC) and anterolateral entorhinal cortex (aLERC). Yet how these regions functionally interact and how aging affects them remain unclear. Using brain imaging and eye-tracking, we show that both regions help detect object novelty in younger adults, with each sensitive to different kinds of novelty. In older adults, these responses were reduced, and eye movements no longer reflected memory for previously seen objects. These findings reveal how the PRC and aLERC work together to support object recognition and how aging disrupts this system—particularly when distinguishing objects based on how their parts are arranged.

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Introduction

The ability to distinguish between objects is supported by the ventral visual stream (VVS), a brain pathway critical for visual perception (Mishkin et al., 1983). Whereas discrimination between dissimilar objects can be solved using single feature representations in early visual areas in the posterior VVS, discrimination between highly similar objects recruits object-level representations in the anterior VVS (Bussey and Saksida, 2007). The representational-hierarchical account of object processing (Saksida and Bussey, 2010; Martin and Barense, 2023) posits that the VVS extends into the medial temporal lobes (MTL) to interface with the perirhinal cortex (PRC), where representations are characterized by the conjunctive coding of object features (Erez et al., 2016). Thus, PRC damage in nonhuman (Buckley et al., 2001; Bussey et al., 2003) and human (Barense et al., 2012; Erez et al., 2013) primates results in compromised discrimination between complex objects sharing multiple features (i.e., cannot be discriminated based on single features). Similar—albeit subtler—deficits are seen in nominally healthy aging (Gellersen et al., 2023; Jiang et al., 2024), as PRC neurodegeneration can appear before diagnosis of dementia (Bastin and Delhaye, 2023).

Recent evidence linked volume of the anterolateral entorhinal cortex (alERC), a PRC-adjacent MTL region, to the ability to differentiate among conjunctive objects based on the spatial (i.e., configural) arrangement of their component features (Yeung et al., 2017). Consistent with findings that rodent lateral ERC—the putative homolog of the human alERC—responds to objects' spatial properties (Knierim et al., 2014), alERC gray matter volume among older adults with varying levels of cognitive decline positively correlated with configural processing, as indexed by eye fixations to objects' middle section. Feature configurations overlapping in this section allowed participants to distinguish between *repeated* (familiar features, familiar configuration), *recombined* (familiar features, novel configuration), and *novel* (novel features, novel configuration) objects, with greater fixations to this section reflecting increased exploration of the object's configural arrangement. The alERC is an early site of dementia-related neurodegeneration (Olsen et al., 2017; Kulason et al., 2020) and shows age-related changes during object discrimination with the PRC (Berron et al., 2018; Reagh et al., 2018); whether this MTL region is functionally sensitive to objects' configural properties has not yet been investigated. Critically, novelty discrimination can rely on feature-level (where all object features are novel) and configural-level (where features are familiar but rearranged in novel configurations) changes, and the PRC/alERC may play distinct roles in representing these forms of change—roles that may also be differentially affected by aging.

Functional activation differences between the PRC/alERC during object processing may be subtle, given their anatomical proximity (Kivisaari et al., 2020) and shared connectivity profiles (Navarro Schröder et al., 2015). Compounding this challenge is considerable interindividual boundary variability, especially with aging (Taylor and Probst, 2008). Foundational studies linking PRC activation to discriminating objects based on their feature conjunctions (Barense et al., 2012; Ryan et al., 2012; Cacciamani et al., 2017) relied on a probabilistic map (Devlin and Price, 2007; Holdstock et al., 2009), overlapping with alERC (Maass et al., 2015). While this approach has been instrumental in understanding MTL function, defining PRC/alERC boundaries in subject space will further establish their respective roles in complex object processing.

Here, we examined functional contributions of the PRC/alERC to configural processing across the lifespan, manually delineating them based on an established segmentation protocol (Yushkevich et al., 2015; Olsen et al., 2017). Participants completed a combined fMRI and eye-tracking task, adapted from Yeung et al., in which they viewed *repeated*, *recombined*, and *novel* objects composed of two unique features (Fig. 1). Gaze fixations indexed memory independent of overt task demands (Hannula et al., 2010), reducing cognitive load for older adults. Given its role in representing the feature conjunctions that compose complex objects, we predicted that the PRC in younger adults would be sensitive to object novelty at both the feature- and configural-level and that this sensitivity to object novelty would be reduced in older adults. Importantly, since the alERC's functional role in configural processing remains less understood, the current study allowed us to probe how this region may contribute to detecting configural novelty—and how this may be impacted by aging.

Materials and Methods

Participants

Forty-nine younger adults (19–35 years old) and 55 community-dwelling older adults (60+ years old) were recruited from the greater Toronto city area. All participants had normal or corrected-to-normal vision and were screened for color blindness, psychological and/or neurological disorders, brain damage (i.e., stroke, surgery, concussions), and metal implants/health conditions that would have precluded MRI. In total, three older adult and four younger adult participants did not meet inclusion criteria of completing at least five of the seven experimental task fMRI runs due to drowsiness or excessive head motion within the scanner. Additionally, one younger adult participant's data corrupted in the transfer of raw DICOM files from the scanner and so was also excluded from all subsequent analyses. One older adult participant was excluded because they scored below 20 on the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005), likely indicative of cognitive decline consistent with dementia (Roalf et al., 2013). Finally, five participants (four older adults and one younger adult) were excluded from fMRI analyses due to poor signal quality in the MTL, i.e., a temporal signal-to-noise ratio 2 SD below average in either the PRC or alERC. Thus, our final sample included 47 older adult participants ($M_{\text{age}} = 72.60$ years; $SD_{\text{age}} = 5.55$; $M_{\text{MoCA}} = 26.55$; $SD_{\text{MoCA}} = 2.00$; $n_{\text{female}} = 33$) and 43 younger adult participants ($M_{\text{age}} = 21.44$ years; $SD_{\text{age}} = 2.52$; $n_{\text{female}} = 32$). The study was approved by the Research Ethics Boards at the University of Toronto and the Rotman Research Institute at Baycrest Health Sciences, and informed consent was given by each participant prior to participation.

Stimuli and contrasts of interest

We used the Strata Design 3D CX 7.0 software (Strata Mixed Reality, 2012) to build a set of conjunctive objects consisting of two distinct upper and lower feature parts which overlapped in the middle third of the object (Fig. 1). These feature parts were unique from one another based on shape, color, and/or texture. The objects were standardized to have the same vertical size of 300 pixels to facilitate their presentation in the scanner. As such, all objects had the same vertical height but ranged in horizontal width between 137 and 563 pixels. Objects were organized into 14 experimental blocks of 21 trials each (two experimental blocks per functional scanning run). Object features were unique to each block, making each block independent. Each block began with five repetitions of three objects (containing features AB, CD, and EF), such that participants saw all three objects in a randomized order before seeing them again (Fig. 1A). Crucially, Repetitions 6 and 7 within each block contained the same *repeated* object (containing familiar features in a familiar configuration, i.e., object AB), two *recombined* objects (containing familiar features in novel configurations, i.e., objects CF and ED), and two *novel* objects (containing novel features in novel configurations, i.e., objects GH and IJ). Objects were counterbalanced such that across

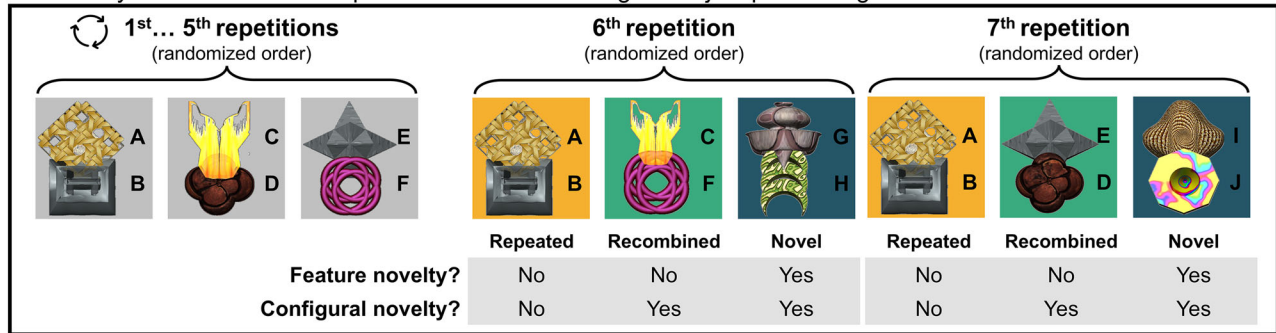
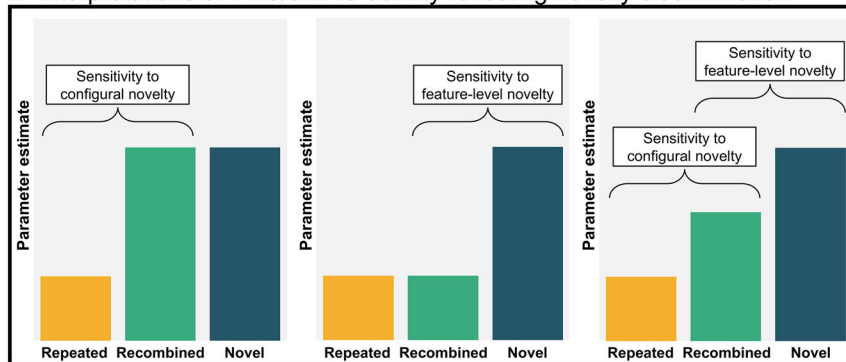
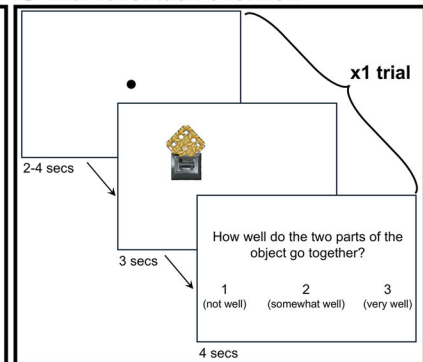
A Novelty conditions in one experimental block of configural object processing task**B** Interpretations of PRC/aERC activity reflecting novelty discrimination**C** Trial-level task overview

Figure 1. Schematic overview of study paradigm. **A**, One experimental block (out of 14 total) of the configural object processing task. Individual object features are denoted by letters A–J. Objects AB, CD, and EF (shown in gray boxes) were presented five times each during Repetitions 1–5 in the experimental block (in randomized order), with the same top and bottom feature parts in a consistent configuration. During Repetitions 6 and 7 of each experimental block, participants saw objects as *repeated* (shown in yellow boxes: familiar features, familiar configurations), *recombined* (shown in green boxes: familiar features, novel configurations), and *novel* (shown in blue boxes: novel features, novel configurations). **B**, Interpretations of novelty discrimination at the feature- and configural-level in PRC/aERC activation. **C**, Example of one trial of the experimental task. Participants saw a fixation cross (2,000–4,000 msec), followed by one object in the viewing phase (3,000 msec) appearing at one of seven evenly spaced positions along a 200 pixel radius circle. Finally, they were asked to rate the coherence of the object's features, using a button box (4,000 msec). A video demonstration of one block of the experimental task, as well as the stimuli used in this experiment, is available on our OSF repository (see Data Availability).

participants any given upper or lower feature half could be part of an object that was *repeated*, *recombined*, or *novel*.

Critically, our stimulus set allowed us to investigate activity in the PRC/aERC, as well as in gaze behaviors, when viewing objects with different levels of novelty (Fig. 1A): objects where nothing has changed (*repeated*), where the configuration has changed (*recombined*), and where both the features and the configuration have changed (*novel*). Moreover, targeted contrasts characterized PRC/aERC detection of object novelty (in Repetitions 6 and 7 of each block) at a global level (*novel* vs *repeated* contrast; the novel object is novel in terms of both its features and configurations), a feature level (*novel* > *recombined* contrast; both configurations are novel, and so novelty is determined by the features), and a configural level (*recombined* > *repeated* contrast; all features are familiar, and so novelty is determined by their configuration; Fig. 1B). Here, we operationalize novelty detection as increased activity for the univariate contrast of interest (Kumaran and Maguire, 2006; see Ranganath and Rainer, 2003 for review).

Procedure

Participants viewed individually presented objects subtending $\sim 4.6^\circ$ visual angle in height. These objects were jittered at one of seven evenly spaced positions along a 200 pixel radius circle (distance from center, 3.09° visual angle). Each trial contained three phases: (1) the fixation phase, (2) the object viewing phase, and (3) the coherence rating phase (Fig. 1C). During the fixation phase, participants were instructed to maintain their gaze on a crosshair presented in the center of the screen (on-screen coordinates in pixels: [960, 540]). The duration of the fixation phase was jittered to last 2–4 s in length. Next, in the object viewing phase, a single object comprising unique upper and lower features appeared at one of the seven circumscribing positions for a duration of

3 s. During this phase, participants were instructed to carefully view the object and determine (without responding) whether the upper and lower features went together coherently. Finally, during the coherence rating phase, a question appeared on the screen ("How well do the two parts of the object go together?") along with three response options (1, not well; 2, somewhat well; 3, very well). Participants were given 4 s to respond to the question by pressing the "1," "2," or "3" button on an MR-compatible four-button keypad held in their right hand. Participants were instructed (and reminded) that this rating was entirely subjective and could change throughout the course of the experimental task.

Eye-tracking

The experimental task was presented on a 32-inch monitor (1,920 × 1,080 resolution) projected on an MR-compatible LCD screen at a distance of ~ 134 cm and viewed with a mirror mounted to a 32-channel head coil. Eye-tracking was recorded using an EyeLink 1000 Plus on a long-range mount, focused on the participants' right eye (sampling rate, 1,000 Hz; spatial resolution $< 0.1^\circ$; accuracy, 0.5°). Participants requiring corrective lenses were provided with a pair of MR-compatible goggles with lenses matching their prescription. Prior to beginning the experimental task and before each functional run, nine-point calibration and validation were performed to ensure stable fixations. Before entering the MRI, participants were provided with task instructions emphasizing that they would see objects on the screen throughout the experiment and that they should inform the experimenter if their field of view (FOV) of the screen was obscured by the head coil in any way (in which case, their head position would be adjusted). Task instructions were also repeated on-screen before each block of the task. Events not defined as saccades or blinks were classified as fixations. For each participant, the number

of fixations made during the experimental task for each object was calculated and exported using EyeLink software Data Viewer.

Behavioral data analyses

Gaze fixation analyses. We were unable to reliably assess the proportion of gaze fixations to the middle section of each object as a measure of configural processing reported in Yeung et al. (2017) for the following reasons: (1) the inherent constraints of eye-tracking during fMRI scanning (e.g., head coil shape, tendency of participants to partially close their eyes while lying on their back, lost calibration midfunctional run), (2) the reduced visual size of stimuli (i.e., smaller visual angle) relative to the ones presented in Yeung et al. outside the MRI scanner, and (3) the shortened object viewing phase (3 s) from the object viewing phase in Yeung et al. (5 s). Consequently, participants in the current study made fewer fixations to the objects and there was increased noise in gaze coordinate measurements (Hanke et al., 2020). Instead, we investigated three eye-tracking-based outcome variables for each novelty condition in Repetitions 6 and 7 of each experimental block: (1) average number of fixations to the conjunctive objects per trial, (2) average durations (in msec) of fixations to the conjunctive objects, and (3) average durations (in millisecond) of the first five fixations to each trial's conjunctive object. In younger adults, prior work has shown a reduction in the number of fixations directed toward previously viewed stimuli, with a corresponding increase in the duration of fixations (Heisz and Ryan, 2011). In contrast, eye movement fixations in older adults are consistently characterized by less differentiated viewing patterns between previously experienced and new stimuli [Whitehead et al., 2018; see also Ryan et al. (2021) for a comprehensive review]. As such, we expected fewer fixations—paired with longer fixation durations—directed to *repeated* objects among younger adults compared with *novel* and *recombined* objects and compared with older adults, reflecting prior experience with these objects and their feature configurations. Furthermore, early fixations within each trial may reflect the speed and/or strength of memory-based signals for objects with which we have prior experience (Ryan et al., 2007). Thus, the inclusion of the third measure—average duration of the first five fixations—permits an examination of how quickly prior experience with features and their configurations exerts an effect on visual sampling within a trial. Even when the average fixation duration across the whole trial may be relatively well predicted by the number of fixations, the duration of each fixation within the trial may vary considerably, and in different ways at different points in the trial for younger versus older adults. We expected early fixations to be directed longer at *repeated* objects, reflecting prior experience with these objects, and later fixations to be directed longer at *novel* objects. Importantly, this third measure of gaze fixations allowed us to examine whether early fixations to *recombined* objects more closely mirrored the pattern of fixations for *repeated* or *novel* objects or a combination of both.

We ran a series of linear mixed-effects models (LMEM) for each of these gaze fixation measures, with interactions of novelty condition (*repeated**, *recombined*, *novel*) and age group (*younger**, *older*) as fixed effects. Random intercepts for participant and image were also included in the models. Backward model comparison ($\alpha = 0.05$) was used to determine the most parsimonious model (p values approximated with the lmerTest package; Kuznetsova et al., 2017) in R (ver. 4.0.0, R Core Team, 2020) for RStudio (RStudio Team, 2020).

Coherence rating analysis. Trial-level coherence ratings ("How well do the two parts of the object go together?") were analyzed using a LMEM with an interaction specified between novelty condition (*repeated**, *recombined*, *novel*) and age group (*younger**, *older*) as fixed effects. Random intercepts for participant and image were also included in this model. Backward model comparison ($\alpha = 0.05$) was used to determine the most parsimonious model, following the same analysis steps as specified for the gaze fixation measures specified above. This measure allowed us to examine how prior exposures to features and their configurations would influence subsequent configural processing, without requiring a direct measure of mnemonic recognition that may have added negative influences of stereotype on task demands for older

adults (Rahhal et al., 2001; Ryan and Campbell, 2021). In this way, implicit and/or explicit mnemonic influences could be captured by an indirect coherence judgment (for further discussion on indirect task requirements, see Ryan, 2012). Missed trials (i.e., trials in which the participant did not respond during the 3 s coherent rating period) were infrequent and were excluded from the coherence rating analysis. In Repetitions 6 and 7, no younger adults missed responses; among older adults, one participant missed 1 trial, and two participants missed 12 trials each. The inclusion or exclusion of missed trials in the LMEM did not change the overall pattern of results. Finally, we assessed response-time variability (in millisecond) of coherence ratings, which could be sensitive to attentional lapses, using an LMEM with an interaction specified between novelty condition and age group as fixed effects. Random intercepts for participant and image were also included in the full model. Backward model comparison was used in the same approach as the LMEM specified above for coherence ratings.

MRI data acquisition

Structural MRI data were acquired on a 3 T Siemens Magnetom Prisma MRI scanner at the Toronto Neuroimaging Facility (University of Toronto) using a 32-channel receiver head coil. Images were collected using a T1-weighted high-resolution MPRAGE sequence [224 slices; FOV, 256 mm; 1 mm isotropic resolution; 0.5 mm interslice spacing; echo time (TE), 2.40 ms; repetition time (TR), 2,000 ms]. High-resolution T2-weighted structural images were also acquired in an oblique-coronal plane perpendicular to the long axis of the hippocampus (42 slices; FOV, 220 mm; 2.0 mm anisotropic resolution; 0 mm interslice spacing; TE, 68.00 ms; TR, 4,220 ms). For older adult participants, we collected two separate T2-weighted structural images to guard against greater movement with aging in the MRI. We qualitatively reviewed each set of T2-weighted images to select one for segmentation. Functional images were acquired using a T2-weighted multiband EPI procedure with oblique orientation and partial coverage focused on the MTL, extending from the early visual cortex (i.e., the inferior top of the occipital lobe) to the anterior temporal lobe (51 slices; FOV, 220 mm; 2 mm isotropic resolution; 0 mm interslice spacing; TE, 30.00 ms; TR, 1,500 ms). Two hundred and eighty volumes were acquired for each fMRI run. A maximum of seven functional runs (minimum five functional runs) using this multiband EPI procedure were acquired while participants completed the experimental task.

Region-of-interest (ROI) definitions

Manual segmentation of gray matter volumes in the MTL on T2-weighted structural scans followed the Olsen–Amaral–Palombo (OAP) protocol (Olsen et al., 2013; Yushkevich et al., 2015), supplemented with a modified version of the protocol for subdivisions of the ERC (Olsen et al., 2017, based on Maass et al., 2015; Fig. 2). The OAP protocol was informed by guidelines established in Insausti et al. (1998) for delineating the PRC and ERC based on cytoarchitectonic analyses of necropsy cases and MR volumetry in health volunteers. The wide age range of both the histologic (12–110 years) and imaging (21–79 years) subjects in Insausti et al. facilitates the application of the OAP protocol to younger and older adult participants in the current study. Note that this protocol matches the one reported in Yeung et al. (2017) but with 2-mm-thick slices (instead of 3 mm) for T2-weighted structural scans. The thickness of slices informs not only the number of slices that are available to segment but also the visibility of boundary landmarks between the PRC and subregions of the ERC. Two independent raters (NLW and SDA) manually segmented the two MTL cortices of interest (PRC, aERC), as well as adjacent MTL cortex divisions (posteromedial ERC and parahippocampal cortex) and three hippocampal subfields [cornu ammonis (CA) 1, dentate gyrus (DG) + CA3, and subiculum] on coronal slices of T2-weighted structural scans using ITKSnap ver. 4.0.0 (www.itksnap.org; Yushkevich et al., 2006). Segmentations for the PRC and aERC were used as subject-specific binarized masks to constrain subsequent ROI analyses of functional activation. A custom script using the R package oro.nifti (ver 0.11.4; Whitcher et al., 2011) was used to extract individual ROIs from each hemisphere into separate NIFTI files for subsequent analyses. Finally,

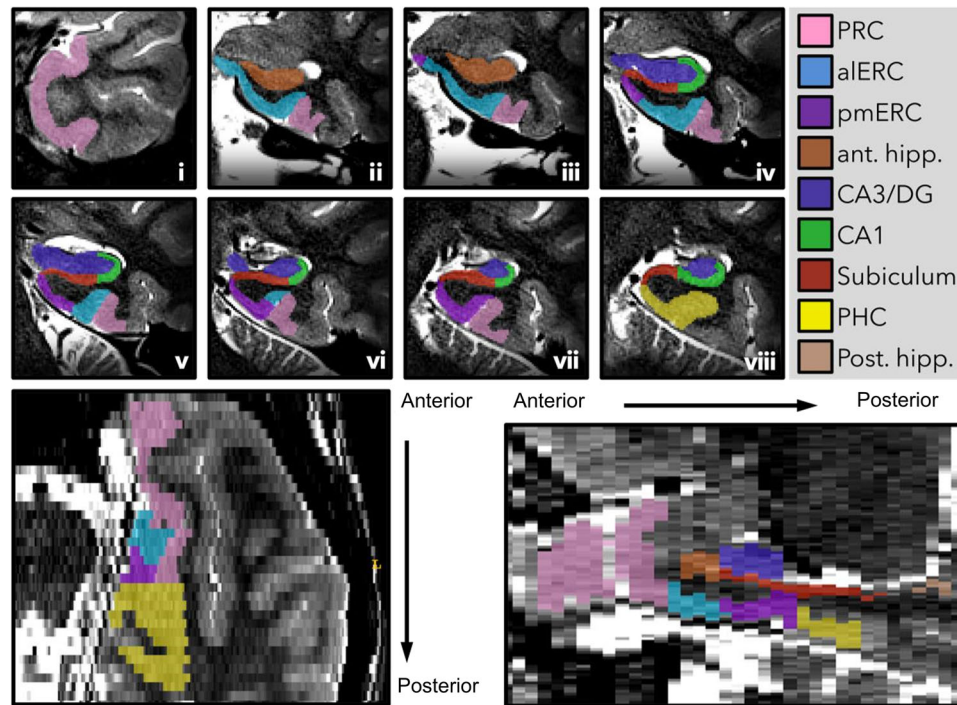


Figure 2. Modified version of the OAP segmentation protocol for gray matter volume in the MTL used in the current study. PRC and aERC are shown in pink and light blue, respectively. Inset images depict coronal slices of the MTL taken at various points along the long axis of the hippocampus. Lower images depict axis (left) and sagittal (right) views for reference.

in order to investigate structural variance in the MTL between age groups, raw volumes of each ROI were adjusted for the head size using a regression-based method, accounting for differences in the brain size between participants. Specifically, raw ROI volumes were corrected for intracranial volume (ICV), estimated using the Computational Anatomy Toolbox (CAT12) pipeline (neuro-jena.github.io; Gaser et al., 2024) in SPM12 (Statistical Parametric Mapping, Wellcome Trust Centre for Neuroimaging, University College London), which serves as a proxy for the head size (Buckner et al., 2004).

fMRI data preprocessing

Structural and functional images were first converted from the scanner's native DCM format into NIFTI using the function `dcm2nii` (Li et al., 2016). To prepare for coregistration, the T1- and T2-weighted structural images were skull-stripped using the brain extraction tool (BET; Smith, 2002) in FSL (manual centering flag = `-c 80 80 180`). For T2-weighted structural images, the fractional intensity threshold was adjusted ($-f = 0.05$) due to underextraction of the skull tissue. Resulting brains were manually inspected to ensure that the neck and shoulders were properly removed and that all gray and white matters were preserved. Next, we used the linear registration tool FLIRT in FSL (Jenkinson et al., 2002) to run a rigid body affine registration of the T2-weighted structural images to the T1-weighted structural images. The transformation matrix produced from this step was also applied to coregister the manually segmented ROI masks to the T1-weighted structural images for each participant. Affine registration using FLIRT was used to transform the T1-weighted structural images to MNI space (MNI152_T1) first, and then FNIRT in FSL (Andersson et al., 2007) was subsequently used to conduct nonlinear registration of the T1-weighted images to the MNI template. For functional images, preprocessing was performed using a series of custom scripts from the FslTools software suite. First, we performed a realignment of every 3D volume to the first acquired 3D volume of that scan using FLIRT. This step also generated motion parameters, indicating a participant's translational and rotational motion over time. These motion parameters were used for quality assurance and later as nuisance regressors in general linear model (GLM)-based analyses. Following realignment, a time-averaged functional 3D volume was calculated using `fslmaths`, which were coregistered to MNI standard space

using the transformation matrix produced from T1-weighted registration.

fMRI analyses

First- and second-level fMRI analyses. First- and second-level analyses, as well as voxelwise whole-brain analyses, were conducted using FEAT 6.00 (Woolrich et al., 2001, 2004) in FSL. Following preprocessing, we calculated a GLM to estimate the activation evoked by objects with varying degrees of novelty (i.e., *repeated*, *recombined*, and *novel*). The comparisons of interest were in Repetitions 6 and 7 of each experimental block, in which objects varied in their feature- and configural-level novelty (Fig. 1A). We included one regressor representing all thirty object presentations encountered during the first five repetitions of each experimental block, modeled as 30 3 s epochs beginning at the same time as each object onset. The two *repeated* object presentations found in the sixth and seventh repetition of each block were modeled as 3 s epochs beginning at the same time as each object onset. Likewise, the *recombined* and *novel* object presentations were each combined in the same manner, resulting in 3 s epochs for the recombined regressor and 3 s epochs for the novel regressor. A fifth regressor was created to represent the response phase of each trial (i.e., the coherence rating phase), modeled as impulses occurring at the onset of each question on-screen. There were 42 such impulses contained within the regressor. Finally, we also modeled the motion parameters as nuisance regressors. The normalized functional data were spatially smoothed using a 3D 5 mm full-width half-maximum Gaussian kernel. BOLD activation for each novelty condition was first averaged within-run for each subject, then across runs within-subject, and finally across all subjects.

ROI analyses. ROI analyses were conducted in the left and right aERC and PRC, using the subject-specific coregistered masks created by manual segmentation of the T2-weighted structural images. The function `fslmeans` from the FSLUTILS toolbox was used to extract parameter estimates from second-level subject contrasts in bilateral ROIs. The first question of interest was to determine how activity in the PRC and aERC was modulated by age and by novelty condition. First, we used parameter estimates in the PRC and aERC in each age group (between: younger, older) to examine sensitivity of these MTL regions to each novelty

condition (within: *repeated*, *recombined*, *novel*), conducted using a mixed ANOVA in R in the package *rstatix* (Kassambara, 2023). Note that we first conducted our analyses specifying hemisphere (within: left, right) for each ROI in the models; in the absence of significant interactions with age group and novelty condition, we averaged across hemispheres. Second, as a follow-up to the primary functional analyses, we tested for age-group differences in ICV-corrected ROI volumes of the PRC and aERC (Olsen et al., 2017; Kulason et al., 2020; Bastin and Delhay, 2023), given that structural variance in the MTL may contribute to age-related reductions in functional activity (Persson et al., 2012). In cases where significant volumetric differences were detected between younger and older adults, the functional mixed ANOVAs were repeated with ICV-corrected ROI volume included as a covariate. Finally, to address our a priori hypotheses about novelty discrimination in both ROIs and age groups, we compared contrasts of parameter estimates for pairs of novelty conditions in younger versus older adults at the global level (*novel* > *repeated*), at the feature-level (*novel* > *recombined*), and at the configural-level (*recombined* > *repeated*). Pairwise contrasts were corrected for multiple comparisons using false discovery rate (FDR). Effect sizes for any significant differences were estimated using Cohen's *d*.

Whole-brain group-level analysis. To explore whether other brain regions showed differences in configural processing effects with aging, in addition to the ROI analysis, we also conducted whole-brain group-level analyses with FSL's FLAME1 mixed-effects function and compared activation with each novelty condition by the age group. The results from this analysis were visualized using BrainNet Viewer (Xia et al., 2013). Whole-brain activation maps depict *z*-stat (3.1) values (cluster inference corrected probability threshold of $p < 0.05$). An atlasquery tool script in

FSL was used to identify the anatomical labels for regions in the Harvard–Oxford cortical atlas that showed significant effects (Supplemental Materials, Table S1).

Parametric modulation analyses. We were also interested in investigating whether a relationship exists between gaze fixation behavior and activation in the brain during configural object processing, so we conducted two parametric modulation analyses using FEAT 6.00 in FSL. Specifically, in addition to regressors of the design matrix described in the main univariate analyses (see above), for each novelty condition in Repetitions 6 and 7 of each experimental block, we added a linear parametric modulation regressor that consisted of (1) trial-wise number of fixations and (2) trial-wise fixation durations. The effect of the fixation modulation regressors in each of the novelty conditions (*repeated*, *recombined*, and *novel*) was first averaged within-run for each subject, then across runs within-subject, and finally across all subjects (i.e., whole-brain group-level analysis) to compare clusters of activation sensitive in each age groups to gaze fixation behaviors during configural object processing.

Results

Behavioral results

To investigate the relationship between gaze fixations to the conjunctive objects and aging, we ran a LMEM on the trial-level number of fixations with interactions of novelty condition (*repeated**, *recombined*, *novel*) and age group (younger*, older) as fixed effects, as well as participant and image as random effects (Fig. 3A). Results of the final best fit model indicated that

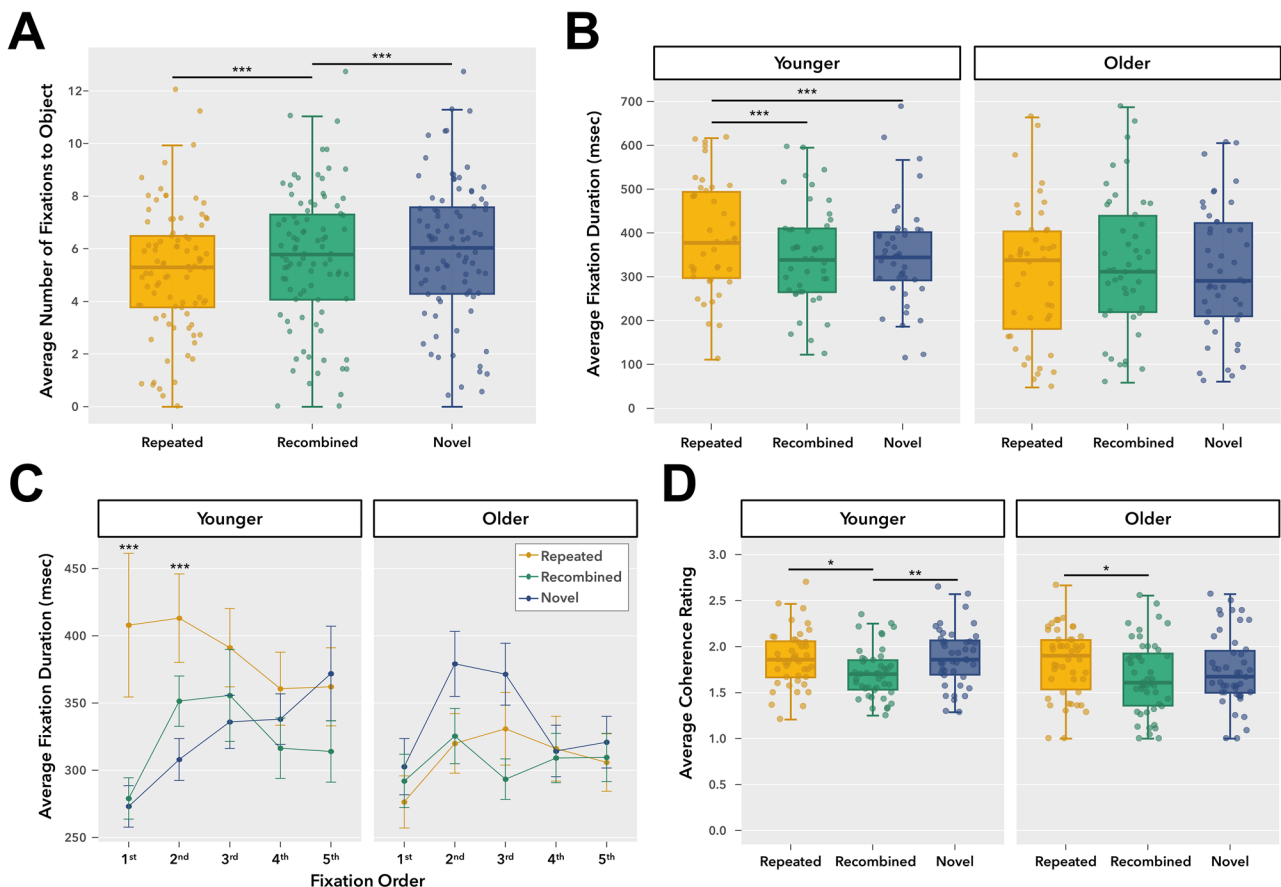


Figure 3. Visualization of gaze fixations and coherence ratings during the configural object processing task. **A**, Average number of fixations per trial for each novelty condition, collapsed across age groups. Error bars represent ± 1.5 * IQR. **B**, Average fixation durations for each novelty condition and age group. Error bars represent ± 1.5 * IQR. **C**, Average fixation duration for each novelty condition and age group, as a function of fixation order. Error bars represent $\pm$ SEM. **D**, Average coherence ratings for each novelty condition and age group. Error bars represent ± 1.5 * IQR. (*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$).

significantly more gaze fixations were made for *novel* relative to *repeated* objects ($\beta = 0.699$; $SE = 0.099$; $z = 7.051$; $p < 0.001$) and for *recombined* relative to *repeated* objects ($\beta = 0.603$; $SE = 0.104$; $z = 5.795$; $p < 0.001$). Gaze fixations did not significantly differ between age groups ($\beta = 0.178$; $SE = 0.542$; $z = 0.969$; $p = 0.597$). The inclusion of the interaction between the fixed effects to the model did not significantly improve the model fit ($\chi^2 = 3.080$; $p = 0.214$).

Next, we investigated the relationship between the duration of gaze fixations to the conjunctive objects and aging by running a LMEM on the trial-level fixation durations with interactions of novelty condition (*repeated**, *recombined*, *novel*), age group (younger*, older), and participant and image as random effects (Fig. 3B). The inclusion of the interaction term between novelty condition and age group significantly improved the model fit ($\chi^2 = 22.349$; $p < 0.001$). Estimated marginal means for post hoc comparisons revealed that older adults did not differ in their gaze duration between any novelty condition (all $ps > 0.05$). In contrast, younger adults made significantly longer gaze fixations for the *repeated* condition compared with both the *novel* ($\beta = 87.57$; $SE = 12.20$; $z = 7.179$; $p < 0.001$) and the *recombined* ($\beta = 83.29$; $SE = 12.50$; $z = 6.667$; $p < 0.001$) conditions. To investigate whether fixation durations varied in length within a trial, we also defined an additional model which included fixation position within each trial (first*, second, third, fourth, fifth fixation) as a fixed effect (Fig. 3C). The further inclusion of the interaction term of fixation position to the model significantly improved the model fit ($\chi^2 = 37.914$; $p = 0.035$). Estimated marginal means were calculated for post hoc comparisons in the interactions. Older adults did not differ in their gaze duration between any novelty condition within each fixation position (all $ps > 0.05$). In contrast, younger adults showed significantly longer gaze durations for *repeated* objects compared with *novel* ones in both the first and second fixation positions ($\beta = 142.83$; $SE = 31.60$; $z = 4.523$; $p < 0.001$; $\beta = 120.84$; $SE = 32.50$; $z = 3.719$; $p < 0.001$) and compared with *recombined* ones in the first fixation position ($\beta = 134.16$; $SE = 32.00$; $z = 4.192$; $p < 0.001$). Finally, younger adults had significantly longer gaze durations compared with older adults for the *repeated* condition in the first and second positions ($\beta = 140.57$; $SE = 39.70$; $z = 3.544$; $p < 0.001$; $\beta = 110.16$; $SE = 40.60$; $z = 2.712$; $p = 0.007$).

Finally, we determined the relationship between judged configural coherence for the objects and aging by running a LMEM on the trial-level coherence ratings with interactions of novelty condition (*repeated**, *recombined*, *novel*) and age group (younger*, older) as fixed effects, as well as participant and image as random effects (Fig. 3D). Results of the final best fit model revealed an effect of novelty condition on coherence ratings moderated by age group ($\chi^2 = 9.528$; $p = 0.009$). Estimated marginal means were calculated for post hoc comparisons in the interaction. Older adults differed in their coherence ratings only for *repeated* compared with the *recombined* ($\beta = 0.151$; $SE = 0.060$; $z = 2.503$; $p = 0.033$) objects, whereas younger adults rated *recombined* objects as significantly less coherent than either *novel* ($\beta = 0.172$; $SE = 0.057$; $z = 3.026$; $p = 0.007$) or *repeated* ($\beta = 0.163$; $SE = 0.061$; $z = 2.646$; $p = 0.022$) objects. Response-time variability to the coherence ratings did not differ between age groups, nor was the effect of novelty condition moderated by age group ($\chi^2 = 0.973$; $p = 0.618$). Participants had shorter response times for *repeated* objects compared with *novel* ($\beta = 124.60$; $SE = 14.10$; $z = 8.862$; $p < 0.001$) or *recombined* ($\beta = 101.70$; $SE = 14.60$; $z = 6.981$; $p < 0.001$) ones, suggesting

that both younger and older adults reacted faster to previously seen objects.

fMRI results

Age-related activation differences in PRC/aLERC to novelty conditions

For both MTL ROIs (PRC, aLERC), there were no interactions with hemisphere by age group ($F_{(1,88)} = 2.377$; $p = 0.127$), hemisphere by novelty condition ($F_{(2,176)} = 2.862$; $p = 0.060$), or hemisphere by age group by novelty condition ($F_{(2,176)} = 0.217$; $p = 0.117$). Therefore, we examined bilateral parameter estimates in subsequent analyses, i.e., averaging across left and right hemispheres for both ROIs. We found a main effect of novelty condition ($F_{(2,176)} = 27.55$; $p < 0.001$; $\eta_p^2 = 0.240$), a main effect of age group ($F_{(1,88)} = 9.405$; $p = 0.003$; $\eta_p^2 = 0.097$), a main effect of ROI ($F_{(1,88)} = 16.705$; $p < 0.001$; $\eta_p^2 = 0.160$), and a significant three-way interaction between novelty condition by age group by ROI ($F_{(2,176)} = 3.411$; $p = 0.035$; $\eta_p^2 = 0.037$). Next, we decomposed this interaction in each ROI separately to examine their sensitivity to configural processing in younger and older adults via a two-way ANOVA for each ROI.

In the PRC (Fig. 4A), we found a main effect of novelty condition ($F_{(2,176)} = 41.065$; $p < 0.001$; $\eta_p^2 = 0.318$), a main effect of age group ($F_{(1,88)} = 14.060$; $p < 0.001$; $\eta_p^2 = 0.137$), and an interaction between novelty condition by age group ($F_{(2,176)} = 3.788$; $p = 0.025$; $\eta_p^2 = 0.041$). Importantly, one-sample t tests showed that the PRC in younger adults was significantly more active than baseline for the *repeated* ($t_{(42)} = 5.13$; $p < 0.001$; $d = 0.78$), *recombined* ($t_{(42)} = 6.93$; $p < 0.001$; $d = 1.06$), and *novel* ($t_{(42)} = 7.53$; $p < 0.001$; $d = 1.15$) conditions, after controlling for multiple comparisons using FDR correction. In older adults, one-sample t tests revealed that the PRC was significantly more active than baseline for the *recombined* ($t_{(47)} = 2.345$; $p = 0.020$; $d = 0.344$) and *novel* ($t_{(47)} = 2.69$; $p = 0.010$; $d = 0.39$) conditions after controlling for multiple comparisons using FDR correction. Examining parameter estimates in the PRC between age groups revealed that they were significantly greater in younger adults compared with older adults in all novelty conditions, i.e., in the *repeated* ($t_{(88)} = 3.17$; $p = 0.002$; $d = 0.67$), *recombined* ($t_{(88)} = 3.93$; $p < 0.001$; $d = 0.83$), and *novel* ($t_{(88)} = 3.09$; $p < 0.001$; $d = 0.82$) conditions.

In the aLERC (Fig. 4B), we found a main effect of novelty condition ($F_{(2,176)} = 13.076$; $p < 0.001$; $\eta_p^2 = 0.129$) and a main effect of age group ($F_{(1,88)} = 4.164$; $p = 0.044$; $\eta_p^2 = 0.045$), but no interaction between novelty condition by age group ($F_{(2,176)} = 0.167$; $p = 0.847$). Across age groups in the aLERC, we found significant differences in parameter estimates between the *repeated* and *novel* conditions ($t_{(89)} = 4.91$; $p < 0.001$; $d = 0.52$), *repeated* and *recombined* conditions ($t_{(89)} = 3.02$; $p = 0.005$; $d = 0.32$), and *novel* and *recombined* conditions ($t_{(89)} = 2.15$; $p = 0.034$; $d = 0.23$). In younger adults only, one-sample t tests against $\mu = 0$ showed that the aLERC was significantly more active than baseline in younger adults for the *repeated* ($t_{(42)} = 2.22$; $p = 0.024$; $d = 0.34$), *recombined* ($t_{(42)} = 3.05$; $p = 0.005$; $d = 0.47$), and *novel* ($t_{(42)} = 3.49$; $p < 0.001$; $d = 0.53$) conditions, but not in older adults for any novelty condition (all $ts < 0.47$; all $ps > 0.05$, one-sided).

Next, to determine whether age-related structural differences in the MTL should be considered when predicting functional activation, we tested for age-group differences in ICV-corrected regional volume. We observed a significant difference in ICV-corrected PRC volume between older and younger adults ($t_{(88)} = 3.40$; $p = 0.001$; $d = 0.70$) and in ICV-corrected aLERC volume between older and younger adults ($t_{(88)} = 4.88$; $p < 0.001$;

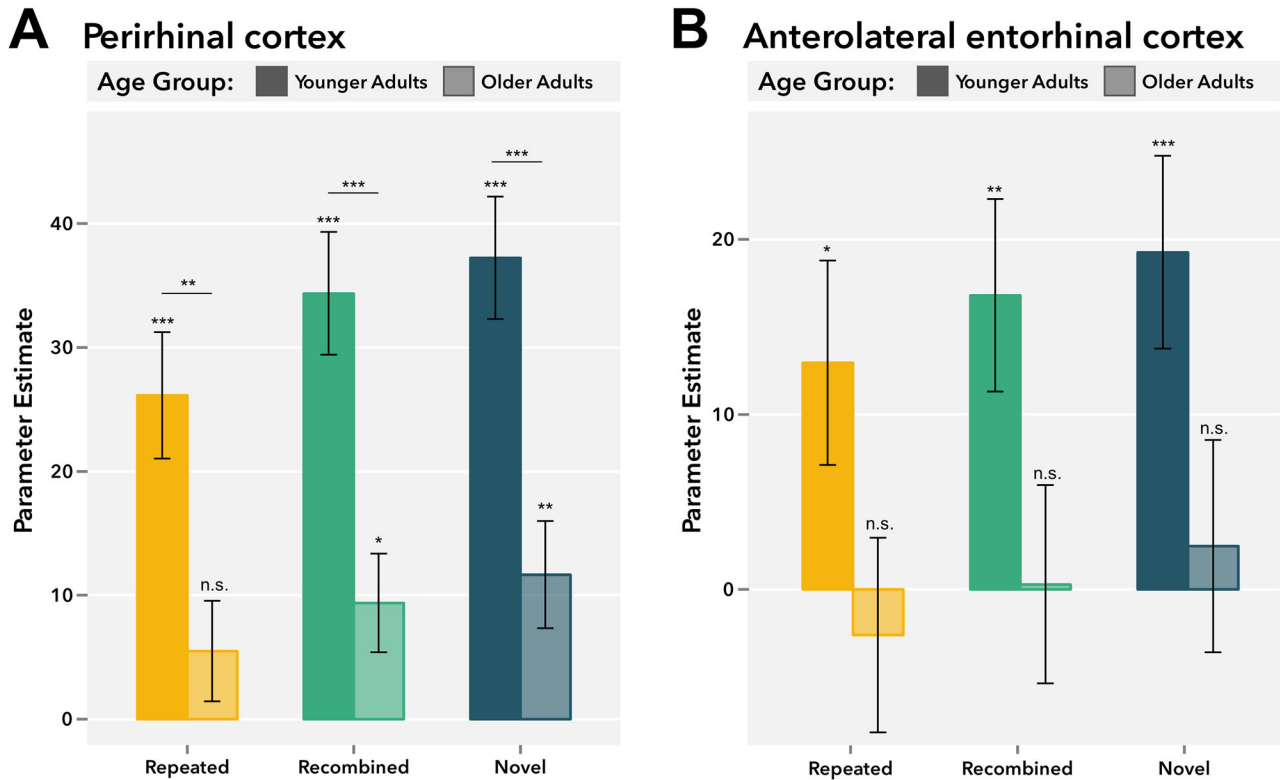


Figure 4. Patterns of activation in PRC and aERC for configural object processing in younger and older adults. **A**, Parameter estimates in the PRC illustrating novelty condition (*repeated* vs *recombined* vs *novel*) differences between age groups (younger, older) on bilateral fMRI activation. **B**, Parameter estimates in the aERC illustrating novelty condition (*repeated* vs *recombined* vs *novel*) differences between age groups (younger, older) on bilateral fMRI activation. (*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; error bars represent $\pm$ SEM).

$d = 1.04$). In the PRC, ICV-corrected volume did not significantly predict functional activation ($F_{(1,87)} = 1.162$; $p = 0.284$) nor did it interact with novelty condition ($F_{(2,174)} = 0.747$; $p = 0.475$). Moreover, the main effect of the age group ($F_{(1,87)} = 9.914$; $p = 0.002$; $\eta_p^2 = 0.102$), the main effect of novelty condition ($F_{(2,174)} = 5.133$; $p = 0.007$; $\eta_p^2 = 0.056$), and the interaction between novelty condition and age group ($F_{(2,174)} = 3.720$; $p = 0.026$; $\eta_p^2 = 0.041$) remained significant after controlling for PRC volume. Similarly, in the aERC, ICV-corrected volume did not significantly predict functional activation ($F_{(1,87)} = 0.064$; $p = 0.801$), nor did it interact with novelty condition ($F_{(2,174)} = 0.128$; $p = 0.880$). In the aERC, we found that the main effect of novelty condition, collapsing across age groups, remained significant when ICV-corrected volume was included as a covariate ($F_{(2,176)} = 12.952$; $p < 0.001$; $\eta_p^2 = 0.128$), but the main effect of age group did not ($F_{(1,87)} = 3.663$; $p = 0.059$).

Feature- versus configural-level novelty PRC versus aERC in younger and older adults

Having established patterns of activation in the PRC and aERC sensitive to configural processing (*repeated*, *recombined*, *novel*) in both age groups (younger, older), we next examined our a priori hypotheses about novelty discrimination in these regions (Fig. 1B), i.e., whether contrasts of parameter estimates distinguished object novelty at the feature-level (*novel* > *recombined*) and at the configural-level (*recombined* > *repeated*).

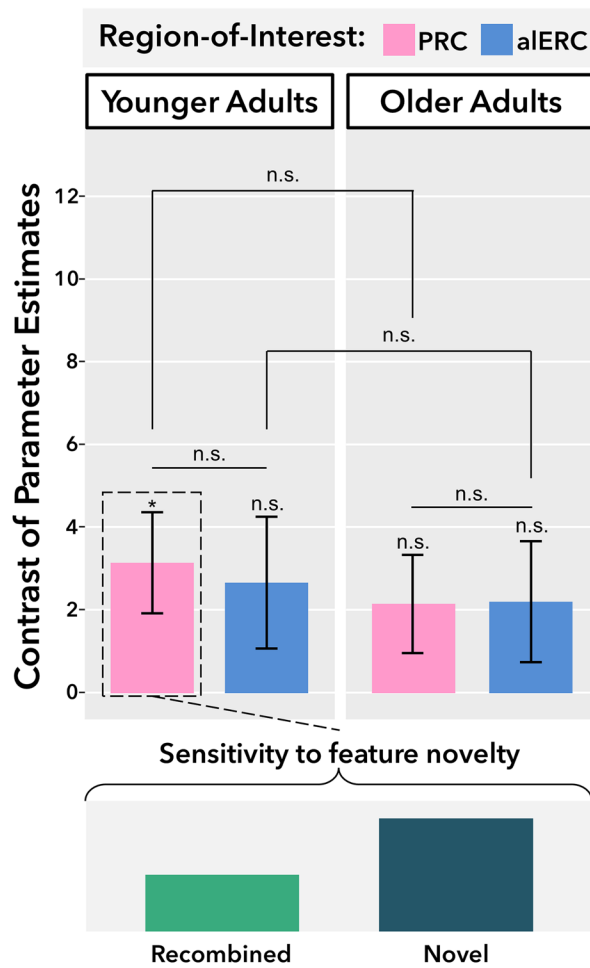
First, we examined whether the PRC and aERC in both age groups were sensitive to novelty discrimination at the feature-level (i.e., *novel* > *recombined*; Fig. 5A). We found that only the PRC in younger adults was sensitive to feature novelty ($t_{(42)} = 2.58$; $p = 0.023$; $d = 0.39$). No other comparisons of interest for

the *novel* > *recombined* contrast were significant (all $ps > 0.05$). Next, we examined whether the PRC and aERC in both age groups were sensitive to novelty discrimination at the configural-level (i.e., *recombined* > *repeated*; Fig. 5B). In younger adults, both the PRC ($t_{(42)} = 5.26$; $p < 0.001$; $d = 0.80$) and the aERC ($t_{(42)} = 2.38$; $p = 0.033$; $d = 0.36$) were sensitive to configural novelty. Moreover, we found that the PRC in younger adults was more sensitive to configural novelty than the aERC ($t_{(42)} = 3.40$; $p = 0.001$; $d = 0.52$). In older adults, however, only the PRC ($t_{(46)} = 3.60$; $p = 0.002$; $d = 0.53$) was sensitive to configural novelty. Importantly, the PRC's sensitivity to configural novelty was greater in younger adults compared with older adults ($t_{(88)} = 2.05$; $p = 0.044$; $d = 0.44$). In summary, the three-way interaction reported in the section above was driven by greater sensitivity to configural novelty in the PRC relative to the aERC, as well as by age-related differences in PRC responses to configural novelty.

For completeness, we examined novelty at the global level (*novel* > *repeated*) in the PRC and aERC. In both age groups, novelty at a global level was reflected in both PRC and aERC activation (all $ps < 0.01$). We also found greater activation in PRC than aERC in younger adults for the *novel* > *repeated* contrast ($t_{(42)} = 3.97$; $p < 0.001$; $d = 0.61$). PRC activation for the *novel* > *repeated* contrast was also greater for younger adults compared with older adults ($t_{(88)} = 2.31$; $p = 0.024$; $d = 0.49$).

Finally, we examined whether ROI sensitivity in both age groups was different for feature novelty compared with configural novelty (i.e., *novel* > *recombined* vs *recombined* > *repeated*). We found a significant difference in the PRC for younger adults ($t_{(42)} = 2.20$; $p = 0.034$; $d = 0.55$), but not for older adults ($t_{(46)} = 1.09$; $p = 0.282$). Sensitivity to feature versus configural novelty

A Novel > Recombined



B Recombined > Repeated

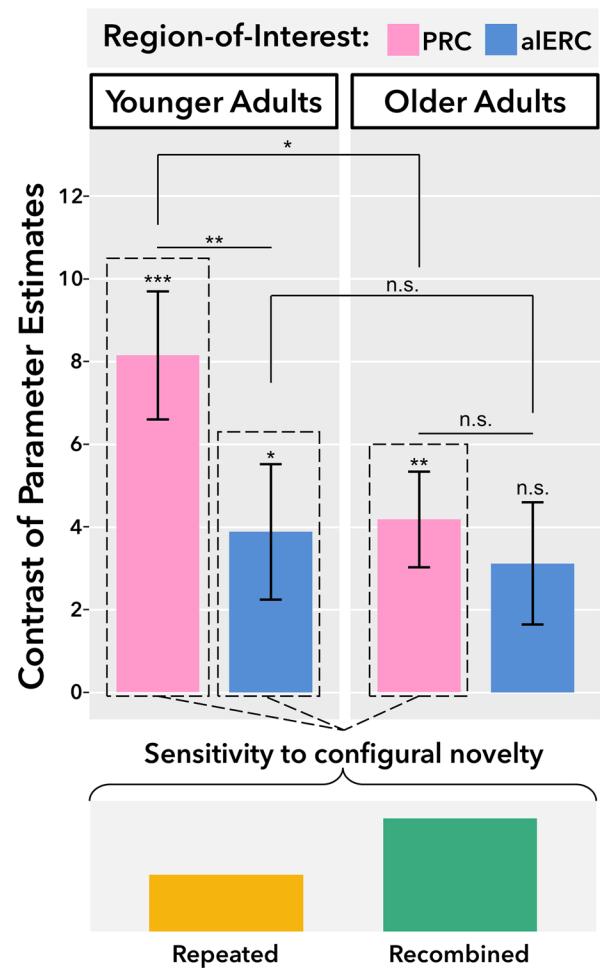


Figure 5. Novelty discrimination at the feature-level and configural-level reflected in PRC (in pink) and aIERC (in light blue) activation between age groups (younger, older). **A**, Feature-level novelty discrimination (*novel* > *recombined*) in the PRC and aIERC in younger (left panel) and older (right panel) adults. The bottom panel shows the interpretation of condition differences (Fig. 1B) reflecting sensitivity to novelty discrimination at the level of features. **B**, Configural-level novelty discrimination (*recombined* > *repeated*) in the PRC and aIERC in younger (left panel) and older (right panel) adults. The bottom panel shows the interpretation of condition differences (Fig. 1B) reflecting sensitivity to novelty discrimination at the level of configural feature arrangements (** $p < 0.001$; * $p < 0.01$; * $p < 0.05$; error bars represent $\pm$ SEM).

did not differ in the aIERC for younger adults ($t_{(42)} = 0.45$; $p = 0.658$) or for older adults ($t_{(46)} = 0.37$; $p = 0.717$).

Whole-brain analyses reveal additional regions recruited for configural object processing

Whole-brain analyses revealed additional age group differences for each of the novelty conditions (Fig. 6). Specifically, compared with older adults, younger adults showed significant clusters of activation in subregions of the occipital lobe (i.e., cingulate gyrus and intracalcarine cortex) and insular cortex, as well as in the pre- and postcentral gyri, for the *repeated*, *novel*, and *recombined* conditions. Additionally, in both the *recombined* and *novel* conditions, younger adults showed significant clusters of activation compared with older adults in the right hemisphere overlapping the frontal orbital cortex, frontal operculum cortex, and insular cortex and bilaterally in an area overlapping the parahippocampal gyrus. Similarly, in the *repeated* condition, younger adults also showed significant activation in the parahippocampal gyrus. For older adults compared with younger adults, we found clusters of activation concentrated in the left precuneus in the *recombined* and *novel* conditions. In the *repeated* condition, older

adults showed a small cluster overlapping with the left lateral occipital cortex, compared with younger adults.

To determine whether additional regions to the PRC/aIERC may have contributed to novelty discrimination between objects, we conducted whole-brain analyses for the *novel* > *recombined* (i.e., feature-level novelty) and *recombined* > *repeated* (i.e., configural-level novelty) contrasts in younger and older adults. No significant clusters differentiating younger versus older adults survived in the *novel* > *recombined* contrast. For the *recombined* > *repeated* contrast, younger adults showed significant bilateral clusters of activation in the lateral occipital cortex, middle frontal gyrus, insular cortex, supramarginal gyrus, and frontal pole (Fig. 7). Older adults, in comparison, showed significant clusters of activation for the *recombined* > *repeated* contrast in the parahippocampal gyrus, precuneus, middle temporal gyrus, and angular gyrus. Finally, we did not find any significant regions of activation for the parametric effects of gaze fixation behaviors on novelty discrimination.

All whole-brain results were thresholded using clusters determined by $z > 3.1$ and a corrected cluster significance threshold of $p < 0.05$.

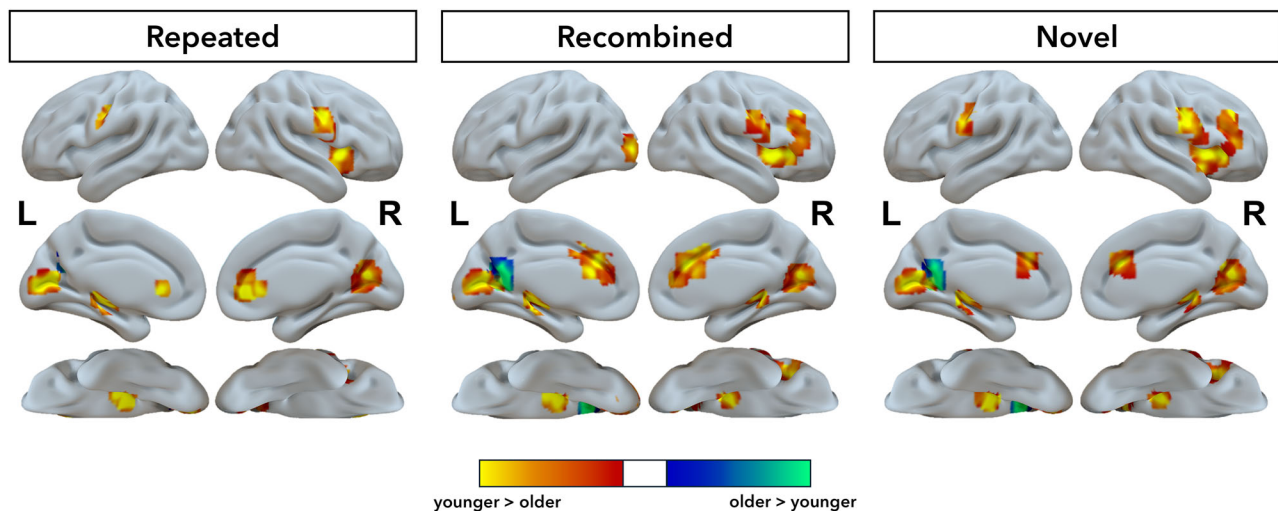


Figure 6. Surface renderings of greater whole-brain activation in younger versus older adults during each novelty condition (*repeated*, *recombined*, *novel*). The top row illustrates lateral surfaces, the middle row illustrates medial surfaces, and the lowest row illustrates ventral surfaces. Hotter colors reflect clusters of activation in younger adults compared with older adults; cooler colors reflect clusters of activation in older compared with younger adults. Results are thresholded using clusters determined by $z > 3.1$ and a corrected cluster significance threshold of $p < 0.05$. Whole-brain coordinates are reported in [Supplemental Materials, Table S1](#).

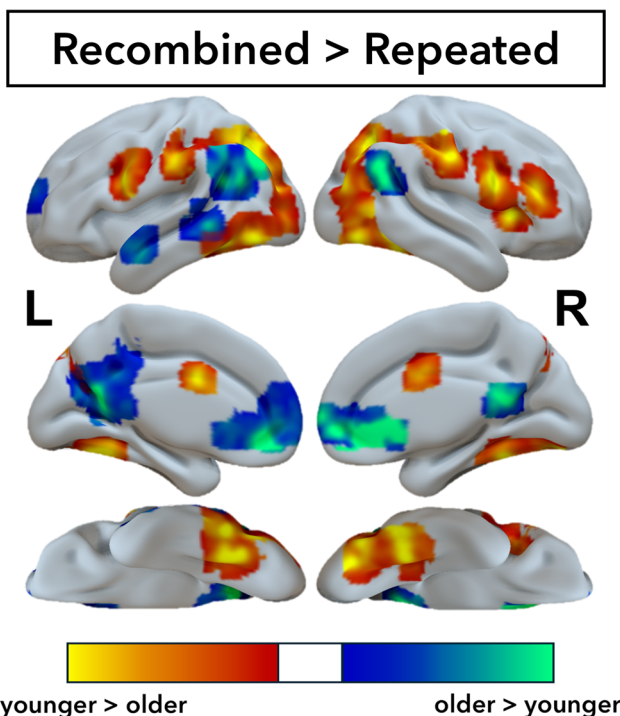


Figure 7. Surface renderings of greater whole-brain activation in younger versus older adults for the *recombined* > *repeated* contrast (i.e., configural novelty). The top row illustrates lateral surfaces, the middle row illustrates medial surfaces, and the lowest row illustrates ventral surfaces. Hotter colors reflect clusters of activation in younger adults compared with older adults, cooler colors reflect clusters of activation in older compared with younger adults. Results are thresholded using clusters determined by $z > 3.1$ and a corrected cluster significance threshold of $p < 0.05$. Whole-brain coordinates are reported in [Supplemental Materials, Table S1](#).

Discussion

The present study demonstrates age-related alterations in PRC/aERC sensitivity to novelty discrimination between conjunctive objects. Novelty was defined by feature-level (all object features were novel) and configural-level (features were familiar but

rearranged in novel configurations) changes. As predicted, PRC activation and patterns of gaze fixation durations in younger adults were sensitive to feature- and configural-level novelty. Age-related decline in discrimination sensitivity was pronounced for configural-level novelty (i.e., distinguishing *recombined* versus *repeated* objects) in the PRC. Our findings also suggest a supporting role of the younger adult aERC for configural-level novelty. In contrast, older adults showed no evidence for PRC/aERC sensitivity to feature-level novelty, nor were gaze fixation durations consistent with novelty discrimination. In older adults, only PRC activation showed sensitivity to configural-level novelty—albeit to a lesser extent than younger adults. Although no direct relationship emerged between gaze fixations and MTL activation, this may reflect the dynamic and distributed nature of eye movements to conjunctive objects, which are not easily captured by trial-averaged signals. Altogether, these results suggest that novelty discrimination between complex objects is supported by the PRC and to a lesser extent the aERC and that aging affects this sensitivity—especially for configural-level novelty.

Consistent with representational-hierarchical accounts of object processing that describe the PRC as representing complex feature conjunctions that compose objects (Saksida and Bussey, 2010; Cowell et al., 2019), the younger adult PRC was sensitive to all levels of object novelty, showing increased activation in response to feature- and configural-level changes. Additionally, in younger adults, the aERC was sensitive to configural-level novelty, although to a lesser extent than the PRC. Representations in the PRC/aERC predict perceived visual similarity among real-world objects (Ferko et al., 2022); our findings extend this prior work by demonstrating that such (dis)similarity may reflect both object features and their configurations. Within the posterior medial–anterior temporal framework, these MTL regions are part of a system that supports fine-grained discriminations by binding object features into integrated representations (Ranganath and Ritchey, 2012). Configural information may be a critical component of what is bound within these conjunctive representations.

Eye-tracking data in younger adults complemented neural findings: viewing to *novel* and *recombined* objects did not

differ. Closer inspection of the trial-level time course revealed that younger adults exhibited longer viewing to *repeated* objects compared with *novel* and *recombined* objects in their earliest fixations, as the associated memory was retrieved. This pattern suggests efficient extraction and evaluation of configural information during initial visual exploration (Ryan et al., 2007; Nahari et al., 2024) and is consistent with evidence that MTL representations of object properties emerge rapidly (Li et al., 2024), even without widely directing gaze across a visual stimulus. Although a relationship between gaze fixations and MTL activation was not found, participants rated *recombined* objects as less coherent than *repeated* objects, suggesting the influence of prior exposures to feature configurations on an indirect judgment, i.e., participants were not instructed to base responses on memory. Age-related differences in attentional disengagement are unlikely to account for the present neural and viewing findings as younger and older adults did not differ in response-time variability to the coherence ratings. Instead, our results suggest that in younger adults, the PRC/aERC operate in concert to support the fine-grained discrimination of feature- and configural-level novelty, alongside adaptive visual exploration that reflects prior exposure to the configural properties of objects and their component features.

In line with previous findings of PRC damage in amnesic patients [see Graham et al. (2010) and Martin and Barense (2023) for reviews] and functional decline in aging (Ryan et al., 2012; Cacciamani et al., 2017), here, PRC activation was markedly reduced for older versus younger adults across novelty conditions. Age-related PRC volume declines were also observed. PRC activation in older adults did not reliably distinguish between *recombined* and *novel* objects, suggesting diminished sensitivity to feature-level novelty with aging. Compared with younger adults, older adults had reduced PRC sensitivity to configural-level novelty (i.e., *recombined* > *repeated*). These results extend prior findings of age-related reductions in domain-specific PRC engagement during object mnemonic discrimination tasks (Berron et al., 2018), to situations in which feature configurations are manipulated. Also, Cacciamani and colleagues (2017) reported age-related decline in PRC sensitivity to configural relationships among features of real-world objects (e.g., lamp); we extend that work by linking PRC function across the lifespan with the rapid formation of configural representations for previously unseen, nonreal objects.

Age-related differences in aERC activation were observed across all novelty conditions, with younger adults showing condition-specific responses. Younger, but not older, adults showed aERC sensitivity to configural-level novelty (*recombined* > *repeated*), which could be related to structural decline in this relatively small MTL region (Olsen et al., 2017; Yeung et al., 2017; Gellersen et al., 2023). Prior work has reported relationships between structural and functional MTL decline in aging (Persson et al., 2012; Ward et al., 2015). However, here, PRC and aERC volumes did not predict functional activation; therefore, volumetric differences alone are unlikely to fully explain the observed functional sensitivity. Future work remains to investigate whether other measures of intraindividual structural decline, such as cortical thickness, predict functional engagement of these regions during configural processing.

Age-related reductions in novelty discrimination for feature- and configural-level changes were also evident in eye-tracking measures. Note that the number of gaze fixations did not differ between groups; rather, older adults directed fixations to objects in a similar manner irrespective of prior exposure to features or

their configurations (Heisz and Ryan, 2011), resembling the viewing behavior of MTL cases (Warren et al., 2011, 2012). Older adults' coherence ratings also did not vary between the *novel* and *recombined* conditions, further suggesting diminished processing of configural features and their arrangements.

Finally, our whole-brain analysis revealed, across all novelty conditions, greater cluster-wise activation in the early visual cortex for younger adults compared with older adults, consistent with recent evidence that older adults exhibit greater inhibition and less engagement of the visual cortex compared with younger adults (Abuleil et al., 2019; Pfeifer et al., 2019). The early visual cortex is thought to represent features with low dimensionality, like simple colors (Hubel, 1982), and is modulated by feedback signals from PRC (Peterson et al., 2012). Relatively lower activation in this region among older adults may reflect lower-resolution representations of early perceptual features. This can have carry-over effects as representational content increases in complexity along the VVS; differences between conjunctive objects presented in varying configurations may have been more difficult for older adults to detect. Indeed, younger adults showed greater activation along the VVS for *recombined* compared with *repeated* objects, suggesting greater recruitment of this object processing stream when differentiating between objects based on configural changes to feature arrangements. Additionally, regions of the dorsal and ventral attention systems were engaged, which support visually guided attentional control (Corbetta and Shulman, 2002) and are well connected with early visual brain regions (Vossel et al., 2014), thereby allowing flexible reorientation toward incoming perceptual input. In younger adults, activation was observed in the right putamen for *novel* and *recombined* objects. Here, the interactions between early visual regions, oculomotor control regions, and the MTL are important to consider (Ryan and Shen, 2020). The putamen is a key region interconnecting memory systems and visuo-oculomotor systems of the brain (Shen et al., 2016); greater elicited putamen activation among younger adults could have been driven by increased coactivation between visuospatial regions and regions supporting complex object representations (i.e., MTL).

Compared with younger adults, older adults showed greater task-related engagement of regions commonly associated with the default mode network (DMN). Older adults often exhibit altered DMN modulation, frequently characterized as reduced task-related suppression and linked to decreased efficiency in shifting toward externally focused processing (Grady et al., 2006). This pattern of whole-brain activation was especially evident in the *recombined* > *repeated* contrast, which required drawing on previously seen features (from memory) and identifying novel arrangements. Older adults may have mistakenly retrieved memories of object parts rather than recognizing a new conjunctive object. DMN engagement may represent age-related overactivation in response to task demands (Qin and Basak, 2020). Precuneus activation, a core DMN region (Utevsky et al., 2014), was notable given previous findings of overactivation in older adults during visual encoding and retrieval (Rajah et al., 2015). Here, it may reflect compensatory processing for poorer MTL object representations, as it has been implicated in prior work with amnesic cases in which mental representations of disparate elements had to be formed (Ryan et al., 2013).

Reliance on configural processing to disambiguate objects may be a unique characteristic of animate biological visual systems (see, e.g., evidence from chimpanzees; Parr et al., 2006). By integrating fMRI, MTL manual segmentation in subject space

and concurrent eye-tracking in both younger and older adults, the current study provides direct functional evidence that the human PRC/aERC are sensitive to configural object properties that support novelty discrimination between conjunctive objects. Taken together, these results reveal important insights into age-related changes in the PRC/aERC to novelty discrimination and advance our understanding of configural object processing in the MTL.

Data Availability

Object stimuli and experimental task demonstration video are openly available on Open Science Framework (OSF) at <https://osf.io/y8u4g/> (doi: 10.17605/OSF.IO/Y8U4G). Processed data and analysis scripts associated with the reported results are available from NLW upon reasonable requests.

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