Age differences in brain activity during perceptual versus reflective attention

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This functional magnetic resonance imaging study presented participants with a face and scene simultaneously on each trial, and assessed the impact of perceptual versus reflective selective attention on activity in parahippocampal place area. Young and older adults showed equivalent activation in parahippocampal place area when cued to attend to the scene when the stimuli were perceptually present and when cued to refresh (briefly think about) the scene after the stimuli were no longer present. The groups also showed equivalent deactivation when cued to attend to the face when the stimuli were perceptually present. However, older adults showed less deactivation than young adults when cued to refresh the face, providing evidence for greater age-related disruption of reflective than perceptual selective attention. ***NeuroReport*** **21:293–297 © 2010 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

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Introduction

Age-related cognitive decline is associated with impaired functioning of executive processes needed to overcome distraction from irrelevant information [1,2]. For example, in a previous functional magnetic resonance imaging study [3], on each trial young and older participants saw two faces and two scenes sequentially in random order. In different blocks, participants were told to remember scenes (ignore faces), remember faces (ignore scenes), or passively view both. Relative to passive viewing, both age groups showed enhanced activity during processing of the study stimuli in an area of posterior cortex sensitive to scenes [parahippocampal place area (PPA)] during remember scenes trials, but only young adults showed reduced activity (i.e. suppression) in PPA during ignore scenes trials. This finding suggests an age-related deficit in suppressing irrelevant information. Furthermore, older adults' failure to suppress PPA activity in the ignore scenes condition was related to reduced accuracy and longer response times, compared with young adults, on the working memory trials, and greater familiarity of to-be-ignored scenes on a later recognition memory test. Gazzaley *et al.* interpreted this pattern (see also Ref. [4]) as supporting the inhibitory deficit hypothesis of aging [1,2]. Converging evidence for the functional importance of suppression of posterior cortex activity associated with irrelevant stimuli is that young adults have better memory for targets when activity associated with nontargets is suppressed [5,6]. Enhancement and suppression of posterior representational areas associated with target and nontarget information, respectively, reflects top–down modulation, that is, attention.

Although these studies have advanced understanding of top–down modulation of posterior regions, the brain activity observed includes a mix of perceptual and reflective attention: Participants presumably engage perceptual attention as each stimulus is sequentially presented and reflective attention (e.g. refreshing, rehearsing) during and/or after presentation of each stimulus. Of course, everyday cognition constantly intermixes perceiving and thinking, but identifying the relative contribution of age-related differences in perceptual versus reflective attention is necessary to more specifically characterize the nature of age-related changes in executive control [1–4,7–11]: Age-related changes need not be equal for perceptual and reflective attention.

This study directly assesses age-related changes in the relative modulatory impact of perceptual and reflective selective attention. Young and older adults saw a face and scene presented simultaneously on each trial (Fig. 1). They were randomly cued either immediately before the stimuli to perceptually attend to one of them (overtly Attend) or after the stimuli to think back to the face or the scene that was just seen but no longer perceptually present (reflectively attend, Refresh). A baseline condition (Act) cued them after the initial stimuli to press a button, but not attend to or refresh either stimulus in particular. In an earlier study [12], compared with baseline, young adults showed enhanced activity both when attending scenes and when refreshing scenes; when ignoring scenes by either attending or refreshing faces, they showed deactivation of PPA. Thus, these findings with young adults show that enhancement or deactivation of PPA occurs during reflective, as well as, perceptual attention depending on whether or not scenes are the focus of attention.

Compared with young adults, older adults are more distracted by perceptually present but irrelevant visual

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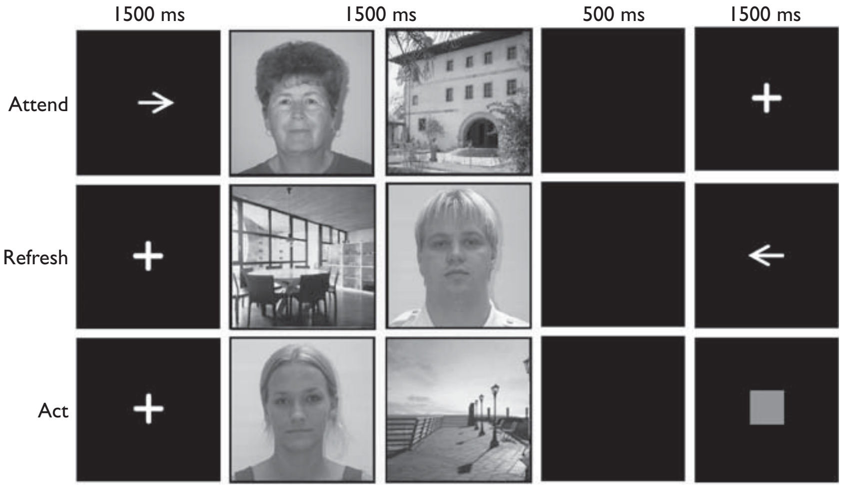
Fig. 1



Trial structure and example stimuli. Face and scene pictures were presented in color.

information, as when participants read text in one font and ignore interspersed text printed in another font [13,14]. Older adults are also more distracted by irrelevant information that is no longer perceptually present, for example, earlier presented stimuli in working and long-term memory tasks [7–9,15]. But, because age-related cognitive deficits tend to be greater when reflective requirements (strategic, effortful processes) increase [10,11,16,17], we expected to find that an age-related deficit in modulation of PPA is more likely when older adults are asked to selectively refresh a scene that is no longer perceptually present than when they are asked to selectively attend to a scene that is present. Such a pattern would provide evidence for greater age-related disruption of reflective than perceptual executive function.

Methods

Participants

Data from 13 healthy, independently living older adults [eight females, mean age = 70.1 years (SD = 5.8; range = 64–85)] were compared with previously collected data from 14 young adults [previously reported [12]; five females, mean age = 21.1 years (SD = 2.8; range = 18–29)]. Participants reported being in good health, with no history of stroke, heart disease, psychotropic medications, or primary degenerative neurological disorder, and normal, or corrected, vision. Older adults scored high on the Folstein Mini Mental State Examination [mean = 29.5 (SD = 0.5); max = 30; Mini Mental State Examination missing from two participants because of time constraints]. There were no age-group differences on an abbreviated version of the verbal subscale of the Weschler Adult Intelligence Scale [$M_{\text{young}} = 24.8$ (SD = 3.0), M_{older} ($n = 12$) = 24.0 (SD = 3.0); max = 30; $t < 1$; $P > 0.10$]; older adults had slightly more education [$M_{\text{young}} = 14.3$ years (SD = 1.8), $M_{\text{older}} = 16.3$ years (SD = 2.8) $t(24) = 2.27$, $P < 0.05$]. All participants were paid and gave informed consent. The Human Investigation Committee of Yale School of Medicine approved the protocol.

Stimuli and procedure

Faces were color frontal headshots of young and older men and women with neutral or pleasant expressions [18]. Scenes were color pictures of landscapes, buildings, and rooms. Stimuli were counterbalanced across participants with respect to condition and run, with each picture used once per participant and faces/scenes appearing equally often on the left and right. The two groups completed parallel pseudorandom trial sequences.

On each trial (Fig. 1), participants saw a face and a scene presented side-by-side for 1500 ms. Attend trials began with an arrow pointing to the left or right (1500 ms), followed immediately by the face/scene stimuli (1500 ms), followed by a blank screen (500 ms) and then a cross (1500 ms). The arrow cued participants to look at (overtly attend to) the picture on the indicated side, and to ignore the picture on the other side. The cued item could be either a face or a scene, yielding Attend Face (Att_F) and Attend Scene (Att_S) conditions. Refresh trials began with a cross (1500 ms), followed immediately by the face/scene stimuli (1500 ms), which were followed by a blank screen (500 ms) and then an arrow pointing to either the left or right side of the screen (1500 ms). The arrow cued participants to think back to (Refresh) the picture that had just appeared on the indicated side. The instructions encouraged participants to visualize the picture. With the brief delay (500 ms) between offset of face/scene stimuli and the cue to refresh, both the face and scene presumably were still active [10,11,19], and the participant was required to selectively reflect on [9] one of these active representations, yielding Refresh Face (Ref_F) and Refresh Scene (Ref_S) conditions. The only difference between the Attend and Refresh trials was that the occurrence of the cross and the arrow were reversed, equating stimulus events in the Refresh and Attend conditions as closely as possible. To avoid evoking additional control processes, no overt responses were required, but earlier studies provide evidence of brain and behavioral consequences of refreshing [8–11,19], including with this exact procedure [12]. For Act trials, face/scene stimuli were preceded by a cross (1500 ms) and followed by a brief blank screen (500 ms) and then a gray square presented centrally (1500 ms), cuing participants to press a button with their right index finger, without thinking about either the face or the scene stimulus. Because identical face/scene stimuli were presented in the Act condition as in Attend and Refresh, but without cues for attentional modulation, it serves as a reasonable baseline condition (analogous to passive viewing, [3]). Trials were separated by blank inter-trial intervals of 3000, 5000, or 7000 ms, randomized for maximal orthogonality between conditions (using Matlab, MathWorks, Natick, Massachusetts, USA).

Participants practiced the task before scanning. The scan session consisted of five runs of 40 trials each, for a total of 40 trials per condition per participant.

Imaging

Data were acquired on a 1.5 T Siemens Sonata. T1 anatomical images were followed by whole-brain echo-planar functional images: 24 interleaved axial slices, repetition time = 2000 ms, echo time = 35 ms, flip angle = 80°, 3.75 × 3.75 × 3.8 mm voxels, 0 mm skip. Each run began with six discarded images (blank screen) to allow steady state magnetization.

Analyses

Data were analyzed using Statistical Parametric Mapping (SPM5; Wellcome Department of Imaging Neuroscience). Preprocessing included slice timing correction, motion correction, coregistration of functional images to the participant's anatomical scan, spatial normalization, and smoothing (9 mm full-width half maximum Gaussian kernel). Spatial normalization used a study-specific template brain composed of the average of the young and older adults' skull-stripped T1 anatomical images (Brain Extraction Tool, FMRIB Centre, Department of Clinical Neurology, University of Oxford, UK; procedure available from investigators). Functional images were resampled to 3 mm isotropic voxels at the normalization stage.

First-level, single-subject statistics were modeled by treating each trial as a 5 seconds epoch (including fixation cross, face/scene pair, and arrow/square), convolved with the SPM canonical hemodynamic response function to create regressors for each condition. Parameter estimates (β images) of activity for each condition and each participant were entered into a second-level group whole-brain random-effects analysis using a mixed 2 (age group: young, older) × 5 (condition: Ref_F, Ref_S, Att_F, Att_S, Act) analysis of variance, with group a between-subjects factor and condition within subjects. From within this group model, the SPM contrast manager was used to identify an area of PPA showing the predicted three-way interaction between condition (refresh/attend), stimulus type (face/scene), and age group (minimum of six contiguous voxels, $P < 0.05$; [20]). We focus on PPA in this report because an earlier study with young adults [12] showed greater modulation in PPA than FFA (see also Ref. [3]). Although we localized the PPA area based on task-related activity, the area identified here as showing the three-way interaction had a local maximum within one voxel of the PPA area reported previously [12] that was confirmed with a separate localizer task. In addition, because young and older adults did not differ in the Attend condition in this area, age differences in the Refresh condition are unlikely to be because of differential success in locating areas of maximal PPA sensitivity in the two age groups. A full list of areas can be obtained from the investigators.

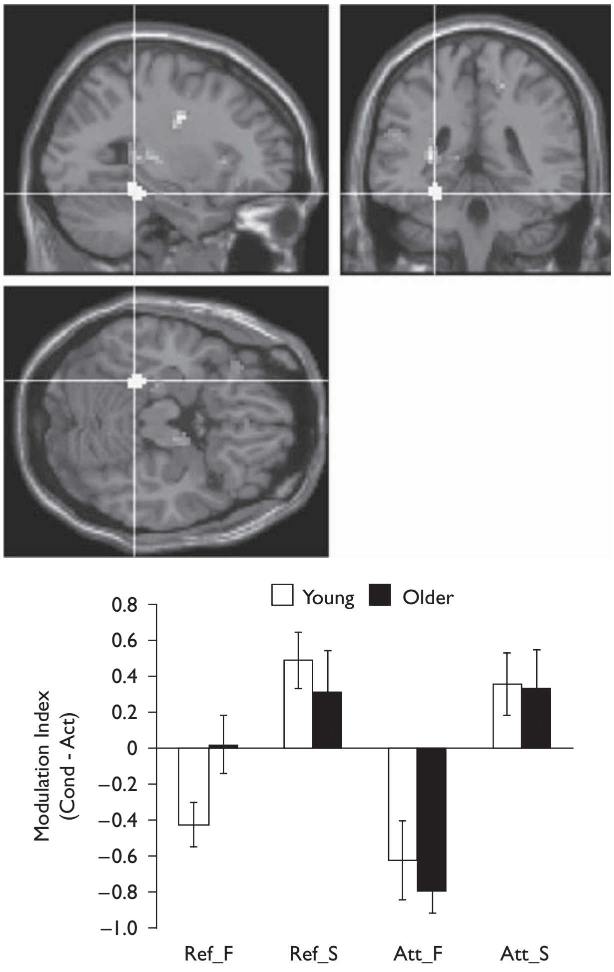
Follow-up analyses used β values for each participant extracted from a 6 mm sphere around the local maximum and averaged to produce a single value. There was no significant difference between young and older adults on Act trials in the PPA region under consideration here ($t < 1$, $P > 0.10$). To control for possible individual differences in preference for faces or scenes, as well as global differences in activation between the age groups, we calculated four 'modulation' indices by subtracting PPA beta values in the Act condition from betas in each of the Refresh and Attend conditions (e.g. Ref_F–Act). Positive values thus indicate activation above baseline (enhancement) and negative values indicate activation below baseline (suppression) [3,12]. Analyses were conducted with these indices to determine condition and age effects, using a mixed 2 (age: young, older) × 2 (condition: attend, refresh) × 2 (stimulus type: face, scene) analysis of variance, with age a between-subjects factor and condition and material type orthogonally crossed within-subjects factors.

Montreal Neurological Institute coordinates were converted to Talairach space using the icbm2tal transform implemented in the GingerALE java tool (v 1.1; *www.brainmap.org*).

Results

Figure 2 shows that, as expected, we identified an area of PPA showing a three-way age × condition × stimulus type interaction [$F(1, 25) = 6.61$, mean square error (MSe) $= 0.15$, $P = 0.02$]. This area showed main effects of condition [mean = 0.10, −0.18, for Refresh and Attend, respectively; $F(1, 25) = 9.34$, MSe = 0.23, $P = 0.005$], and of stimulus type [mean = 0.37, −0.46, for scenes and

Fig. 2



Area of left parahippocampal gyrus (−26, −36, −16) showing an age × condition × stimulus type interaction. Bar graphs show mean difference in β values for the Refresh and Attend conditions, each minus the Act condition (i.e. modulation index), for each age group. Upward-pointing bars represent enhancement of activity relative to the baseline condition (Act), and downward-pointing bars represent suppression relative to Act. Error bars represent the standard error of that mean.

faces, respectively; $F(1,\ 25) = 52.20$, $\mathrm{MSe} = 0.36$, $P < 0.00001$), and a condition × stimulus type interaction [$F(1,\ 25) = 9.00$, $\mathrm{MSe} = 0.15$, $P = 0.0006$]. Most important for current concerns, the three-way interaction arose because the age groups differed significantly only in Ref_F [$t(25) = 2.22$, $P < 0.05$; all other P's > 0.10], with young adults showing greater suppression (i.e. activity below baseline) in left PPA when they were required to refresh faces (mean $\beta = -0.43$) than did older adults (mean $\beta = 0.02$).

Discussion

Participants were shown a scene and face simultaneously and were cued in advance to selectively attend to the scene or to the face, or they were cued immediately after presentation to selectively refresh one of them. We compared activity to a nonselective baseline condition so that we could assess both enhancement (activity above baseline) and suppression (activity below baseline) of PPA separately for perceptual and reflective attention. Compared with young adults, older adults showed intact enhancement of PPA when required to selectively refresh scenes but significantly less suppression of PPA when required to selectively refresh faces (ignore scenes). Older adults' activity in PPA did not differ from young adults' when they were required to selectively attend to perceptually present faces or scenes. Thus, our findings go beyond earlier results [3] in identifying an age-related deficit in suppressing activity in extra-striate cortex that is greater for reflective than perceptual attention. The current findings also help interpret evidence that posterior representational areas such as PPA show less specificity of activation with age for classes of information (e.g. scenes; Refs. [21–23], and reduced activity during long-term memory tasks [24]). This may reflect age-related dysfunction of representational areas, age-related differences in the distribution of attention to stimuli during perceptual or reflective processing, or some combination. Preserved enhancement and suppression in PPA in the Attend conditions in this study provides evidence of preserved PPA function in older adults. Converging evidence for intact representational areas in older adults comes from studies showing that older adults demonstrated less neural adaptation in lateral occipital cortex (sensitive to processing objects), compared with young adults, when freely viewing repeated objects presented on (novel) complex backgrounds, but similar responsiveness in lateral occipital cortex to young adults when explicitly instructed to attend to the objects and when the objects were viewed alone [21]. Thus, apparent loss of differentiated activity, or reduced activity, in posterior representational areas in older adults may in some cases be a consequence of failure to restrict perceptual and/or reflective attention to the target stimulus.

Using event related potentials, Gazzaley *et al.* [4] showed that the age-related deficit in suppression of PPA associated with their working memory task occurred at an early stage of processing (e.g. first 200 ms of stimulus presentation), but that older adults showed intact suppression at later stages (e.g. 500–650 ms after stimulus onset). However, older adults still showed a memory deficit. This is consistent with behavioral findings that older adults can refresh single words, but are slower (in the 150 ms range) to do so than are young adults and reap less long-term memory benefit [11]. There are several possibilities consistent with the present results and those of Johnson *et al.* [11] and Gazzaley *et al.* [4]. A delay in actively inhibiting irrelevant information [1,2] could result in greater interference from active but irrelevant representations that makes refreshing a single item from among competitors more difficult and/or less efficacious for older adults. Alternatively, a delay in actively foregrounding (i.e. refreshing) a single target may decrease the target's discriminability from distractors as all items decay [25]. And yet another alternative is that inappropriate refreshing of irrelevant information makes it a stronger competitor [8], thus increasing interference during reflection, especially for older adults. The relative contributions of these factors, although difficult to disentangle, clearly deserve further investigation.

Conclusion

The current findings are consistent with the proposition that irrelevant information is more likely to remain active in working memory in older adults [1,2]. Although a number of important theoretical and empirical issues remain, the current findings clearly show the importance of distinguishing between age-related changes in executive processes operating during perception and those operating during reflection [10,11] in attempting to clarify the age-related changes in neural mechanisms of cognition.

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