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Lower-Resolution Retrieval of Scenes in Older Adults With Subjective Cognitive Decline

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Abstract

Objective: Scenes with more perceptual detail can help detect subtle memory deficits more than scenes with less detail. Here, we investigated whether older adults with subjective cognitive decline (SCD) show less brain activation and more memory deficits to scenes with more (vs. scenes with less) perceptual detail compared to controls (CON).
Method: In 37 healthy older adults (SCD: 16), we measured blood oxygenation level-dependent-functional magnetic resonance imaging during encoding and behavioral performance during retrieval.
Results: During encoding, higher activation to scenes with more (vs. less) perceptual detail in the parahippocampal place area predicted better memory performance in SCD and CON. During retrieval, superior performance for new scenes with more (vs. less) perceptual detail was significantly more pronounced in CON than in SCD.
Conclusions: Together, these results suggest a present, but attenuated benefit from perceptual detail for memory retrieval in SCD. Memory complaints in SCD might, thus, refer to a decreased availability of perceptual detail of previously encoded stimuli.

Keywords: Memory encoding; Memory retrieval; Older adults; Parahippocampal place area; Scene complexity; Subjective cognitive decline

Introduction

Visual scenes are potent stimuli for examining memory function in aging. Reduced parahippocampal gyrus activation has been reported during the encoding of visual scenes that were nevertheless remembered later on, in healthy older (vs. younger) adults (Gutchess et al., 2005). Parahippocampal gyrus activation during the encoding of scenes is also reduced in patients with mild cognitive impairment (Machulda et al., 2009) and is related to global cognitive status in patients with early Alzheimer's disease (Golby et al., 2005). However, it is unclear whether and how the perceptual information contained in the scenes used as stimuli (and of which participants may not be explicitly aware) may impact memory function in aging. Visual scenes containing more detail activate the parahippocampal gyrus more strongly (during encoding) and are recollected better than scenes with less detail in developmental samples (during retrieval) (Chai, Ofen, Jacobs, & Gabrieli, 2010). Accordingly, scene stimuli with more perceptual detail might hold greater potential for detecting subtle memory deficits in aging conditions where individuals' neuropsychological scores on memory tests are within the typical range, but they experience their memory as worsening. Subjective cognitive decline (SCD) is the perceived decline in cognitive abilities in the absence of objective deficits

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on neuropsychological tests and unrelated to acute events (Jessen, Amariglio, et al., 2014a). SCD can predict decline in episodic memory (Hohman, Beason-Held, Lamar, & Resnick, 2011; Koppara et al., 2015) and progression to mild cognitive impairment (Reisberg, Shulman, Torossian, Leng, & Zhu, 2010), and it may involve altered functional connectivity in episodic memory-relevant networks (Viviano & Damoiseaux, 2020) and visual regions (Contreras et al., 2017). Visual stimulus details of which the observers may not be (or only be partially) aware could directly or indirectly influence memory. Thus, in the present study, we investigated whether and how implicit perceptual details contained in scenes modulate memory encoding or retrieval in older adults with SCD.

The posterior parahippocampal gyrus is part of a functionally defined region, the parahippocampal place area (PPA, including the anterior lingual and medial fusiform gyri; Epstein & Baker, 2019; Epstein & Kanwisher, 1998), which, along with the occipital place area and the retrosplenial complex, is relevant for scene processing (Epstein & Baker, 2019; Malcolm, Groen, & Baker, 2016). The strength of PPA's response to scene compared to non-scene stimuli (i.e., PPA's neural differentiation) is associated with recognition memory for scenes (Koen, Hauck, & Rugg, 2019)—supporting the proposal that it reflects the degree of *precision* of the representation of perceptual information in PPA (Koen et al., 2019). Importantly, PPA's neural differentiation declines with aging (Koen et al., 2019; Park et al., 2004).

Given this, and because we were interested in studying *visual* processing of scenes, we specifically focused on PPA's activation to the perceptual detail contained in scenes but of which participants were unaware. In particular, we aimed to determine whether older adults with SCD benefit less from scenes' perceptual detail, compared to older adults without SCD, during both memory encoding (when the task is to identify the scene's category) and retrieval (when the task is to decide whether the scene was presented earlier). We determined scenes' object load (i.e., the number of *unique* objects composing them) to examine the effect of perceptual detail on PPA activation during encoding and behavioral performance during retrieval, as done previously (e.g., Chai et al., 2010; Yin et al., 2020). We expected three possible outcomes related to, respectively, PPA activation, PPA–behavior relationship, and behavior.

First, PPA's activation is higher for scenes with more versus fewer objects during encoding (e.g., Bar, Aminoff, & Schacter, 2008). Thus, we expected a load by SCD group interaction, with significantly smaller load effects in older adults with versus those without SCD, indicative of reduced encoding of perceptual detail—or "lower-resolution *encoding*"—in SCD. To check the specificity of these effects (and following Koen et al., 2019), we additionally analyzed the lateral occipital complex (LOC), an object-relevant area (Grill-Spector, Kourtzi, & Kanwisher, 2001). We expected higher LOC activation to high-load versus low-load scenes (because high-load scenes contain more of LOC's preferred stimulus), but no interaction with SCD group.

Second, higher PPA activation to scene compared to non-scene stimuli is associated with recognition performance (e.g., Koen et al., 2019). With scene stimuli, a "high-load > low-load" contrast would reflect PPA's neural differentiation, as it involves PPA's preferred stimulus varying only in its information content or "complexity" (Chai et al., 2010; Güçlütürk, Güçlü, van Gerven, & van Lier, 2018). Hence, we expected higher PPA activation to high-load versus low-load scenes during encoding to relate to recognition accuracy. A standard measure of recognition memory accuracy deriving from the Two-High-Threshold Model (for a detailed description, see Snodgrass & Corwin, 1988) assumes that observers apply the same threshold for correctly deciding that an old scene is old (hit response, *H*) and incorrectly deciding that a new scene is old (false-alarm response, *FA*). In practice, these two components of recognition accuracy may be influenced differentially by the degree of perceptual detail encoded in PPA—because additional encoding of perceptual detail can occur with novelty detection during retrieval, which would be more likely to happen with the presentation of new (*FA*) versus old (*H*) scenes in the memory test. Consequently, we additionally explored whether the observed rates of *H* and *FA* responses would differ in how strongly they are related with PPA activation. Aging may especially weaken the ability to guard against false recognition, that is, to tell apart new from old memory items (Dennis, Bowman, & Peterson, 2014; Devitt & Schacter, 2016). Thus, we reasoned that PPA activation to high-load versus low-load scenes might relate more strongly to the *FA* rate (than to the *H* rate), which involves the distinction between new and old scenes.

Third, behavioral performance during retrieval is better for scenes with more (vs. fewer) objects, given their better encoding (e.g., Chai et al., 2010). Accordingly, we expected a load by SCD group interaction, with a smaller load effect in older adults with versus those without SCD, indicative of reduced retrieval of perceptual detail—or "lower-resolution *retrieval*"—in the former, which might or might not be directly related to the (hypothesized) lower-resolution encoding. This expected result would be relatively independent of that for encoding (i.e., prediction 1) because we infer the encoding "resolution" from the activation in only one (of possibly many) brain region(s) relevant for scene encoding, but also because adequate retrieval requires other cognitive processes that do not necessarily play a role for encoding. Following the approach set out with regard to prediction 2, we examined behavioral performance not only for recognition accuracy but also for the *H* and *FA* rates separately. This was done because aging, and perhaps SCD especially, may raise *FA* responses without necessarily decreasing *H* responses (e.g., Dennis et al., 2014; Gutchess et al., 2005). Moreover, it was necessary to account for any load effects reintroduced with stimulus presentation during retrieval, that is, to disentangle effects of object load on the original encoding of "old" scenes from the effects (if any) on the same scenes presented again for the memory test (which should affect the *H* rate) on the one hand, and

Table 1. Demographic data of the study sample

	SCD ($n = 16$) Mean ± *SD*	CON ($n = 21$) Mean ± *SD*	*t*-value (*p*-value)
Age (years)	69.2 ± 7.8	70.7 ± 7.9	−.57 (.574)
Sex (F/M)	15/1	15/6	$\chi^2 = 2.95$ (.109)
Education level	3.4 ± 1.4	2.7 ± 0.8	1.81 (.083)
Handedness	97.5 ± 4.5	96.2 ± 9.6	.55 (.586)
MMSE/30	28.9 ± 1.0	28.4 ± 1.5	1.37 (.179)
Medical help sought owing to complaints (yes/no)[a]	12/4	0/21	**$\chi^2 = 23.31$ (.0005)**
Family history of dementia (yes/no)	9/7	5/16	$\chi^2 = 4.06$ (.074)
Racial identity (black/white)	12/4	20/1	$\chi^2 = 3.18$ (.136)

Note. Levels of education: 1, less than high school; 2, high school; 3, associate degree; 4, 5, and 6: bachelor's, master's, and doctorate degrees, respectively. Handedness is based on the Edinburgh Handedness Inventory (Oldfield, 1971), with positive values approaching 100 indicating complete right-handedness. CON = controls; MMSE = Mini-Mental State Examination; SCD = subjective cognitive decline. Boldface indicates a significant difference between the groups.
[a]As self-reported by participants.

from the effects on "new" scenes shown for the first time during the memory test (which should influence the *FA* rate) on the other hand. If (especially high-load) scenes are encoded with higher resolution during the initial presentation, participants would likely recognize old scenes as old, increasing the *H* rate. Conversely, even if (high-load) old scenes were encoded with higher resolution, new scenes may more likely trigger perceptual detail encoding owing to their perceived novelty, which could either make them easier to reject, decreasing *FA* rates, or give rise to false memories (e.g., owing to some, but not all, encoded objects matching those contained in old scenes), increasing *FA* rates. If SCD individuals have a particular problem with false recognition, their (generally reduced) load effect should be especially expressed in the FA measure.

Materials and Methods

Participants

Fifty-one healthy older adults (53–85 years old) took part in this functional magnetic resonance imaging (fMRI) study. Five participants were excluded due to low global cognitive state (Mini-Mental State Examination <25; $n = 5$). From the remaining 46 participants, two had to be excluded to due task-compliance issues (i.e., 0% hit rate), one due to left-handedness (in an attempt to avoid heterogeneity of potential hemispheric lateralization of cognitive functions, such as language processing), and six due to fMRI data issues (imaging artifacts, $n = 2$; report of opioid medication use before scanning, $n = 1$; and maximum absolute displacement >1.5 times voxel size or 4.2 mm, $n = 3$). This latter data quality-check step ensured that the remaining participants ($n = 37$; 70 ± 7.8 years old; 7 males; 16 with SCD; all demographic data are summarized in Table 1) had complete and reliable fMRI and behavioral data, no recent or past history of neurological disease, psychiatric disorders, head trauma, and no current use of psychoactive medication. They also had normal or corrected-to-normal vision; visual acuity was adjusted during fMRI with scanner-safe glasses if required by the participant.

Participants were volunteers recruited from senior centers and the community of the Metro Detroit area (MI, USA). We defined SCD status by asking participants whether they perceived decline in their memory not related to particular health or personal events, and whether they were concerned about it. Only those who felt worrisome about the perceived decline in their memory were classified as having SCD (SCD group) because previous research has indicated that mainly individuals who are *concerned* about the presence of subjective memory complaints have an increased risk for dementia (Jessen, Wolfsgruber, et al., 2014b). Those who did not report being concerned about such a decline were classified as controls (CON group). The frequency of memory complaints, even though quantified (see *Neuropsychological Assessment*), was not used to form the two groups because it captured neither individuals' concern about their cognitive change directly nor other aspects of cognition relevant to the experience of decline (e.g., attention or executive functions) and because memory complaints are overall frequent in older adults (Molinuevo et al., 2017). The key distinctive aspect of SCD in cognitively unimpaired older adults is the self-reported *feeling* of (subjective) cognitive decline (Jessen et al., 2020). Accordingly, the group definition used in the current study was based on the question about perceived decline in memory and individuals' concern about it. All included participants exhibited normal memory function as determined by adequate global functioning (i.e., Mini-Mental State Examination ≥25) and no more than two indices of the Wechsler Memory Scale-IV (Wechsler, 2009) below 2 *SD* of the normative mean. This cutoff was selected to prevent a risk of misclassifying cognitively normal older adults as mild cognitive impairment, which is very likely when multiple tests are administered to older adults (Brooks, Iverson, Holdnack, & Feldman, 2008;

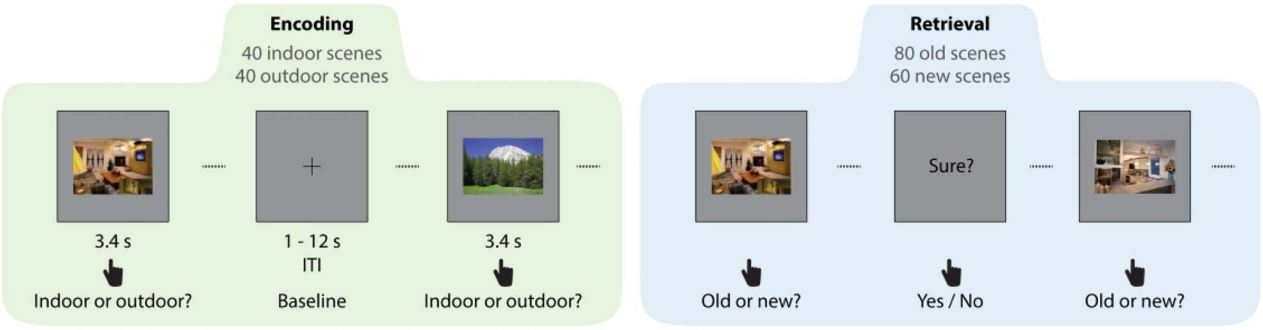

Fig. 1. Encoding and retrieval phases of the scene memory task.

Loewenstein et al., 2006; Mistridis et al., 2015). The Institutional Review Board of Wayne State University approved the procedures used in this study, which complied with the ethical principles of the World Medical Association Declaration of Helsinki. All participants gave their written informed consent before taking part in the study. The current study sample partially overlaps with that reported in (Hayes et al., 2017)[1]. However, the previous study investigated differences in *subsequent memory* (i.e., brain activation to subsequent hits > misses) between older adults with and without SCD, whereas the current study focuses on differences in the effects of scenes' *perceptual* detail (i.e., brain activation to current high load > low load) between older adults with and without SCD, testing independent hypotheses in new analyses.

Experimental Design

Scene memory task. The task consisted of two phases: encoding and retrieval (Fig. 1). Participants underwent fMRI during the first (encoding) phase. In this phase, 80 unique color photographs of 40 indoor and 40 outdoor real-world scenes were randomly presented each for 3.4 s followed by a 1- to 12-s jittered intertrial interval with a fixation cross that served as the baseline (i.e., event-related design) (Fig. 1). Participants viewed the scenes through a mirror mounted at 45° on the head coil and were instructed to memorize the scenes, as they would later be asked to recall them. The immediate task was to indicate whether the scene presented was indoors or outdoors by pressing one of two buttons of a response box placed under the right hand while the scene was still in view. There was a practice session, which included a separate set of photographs, before the scanning, and the instructions were repeated before the task properly started. All scenes were presented in one single run that lasted 10 min 15 s, and the presentation order varied randomly. Eighty fMRI frames were acquired for each of the two conditions of interest (also see *Data Preprocessing and Analysis* for details of the fMRI acquisition). The task was programmed and presented using E-Prime v.2.0 (Psychology Software Tools, Pittsburgh, PA).

Memory recognition was assessed outside of the scanner, about 30 min after the encoding phase, with 140 indoor and outdoor scenes (i.e., 60 intermixed, unique "new" scenes). Note that although the new scenes were photographs of entirely different individual spaces, they were not constrained to represent entirely different scene *categories* (e.g., both old and new stimulus sets could depict two different kitchen settings). Accordingly, new scenes could contain objects from similar conceptual categories as old scenes. Participants indicated whether a given scene was "old" (i.e., presented during scanning) or "new" (i.e., not presented before) and, next, whether they were "sure" or "unsure" of their response (Fig. 1). This task phase was self-paced.

Scenes of both phases (i.e., memory encoding and retrieval) varied in "object load," defined as the number of unique objects contained within the scene (Fig. 2). This number had already been computed for a previous study in a developmental sample (Chai et al., 2010) using the LabelMe toolbox (http://labelme.csail.mit.edu/Release3.0/browserTools/php/matlab_toolbox.php) (Russell, Torralba, Murphy, & Freeman, 2008) and already accounts for the effect of perceptual grouping—i.e., the visual pattern simplification when a scene contains regularities, for example, the many trees in a forest scene (Chai et al., 2010). Based on that number, our scene stimuli belonged to two categories[2]: high load (i.e., five or more unique objects: mean ± *SD*, 8 ± 2.5; range, 5–15) or low load (i.e., three or fewer unique objects: mean ± *SD*, 2.5 ± 0.72; range: 1–3). Following the results of Chai et al. (2010), none of our stimuli had a "middle-load" category (i.e., exactly four unique objects). Accordingly, high-load and

1 Our sample included three new SCD participants (then part of the incomplete data in Hayes et al., 2017) and excluded five of the CON participants due to stricter head-motion criteria in the current study—necessary for the partial volumes in the ventral posterior brain studied here—and task compliance.

2 This categorization was established in Chai et al. (2010), and it was based on the empirical distribution of object categories obtained after labeling the scenes in their study. We used 80 of the scenes of Chai et al. (2010) and, thus, our stimuli had been categorized already *before* our study.

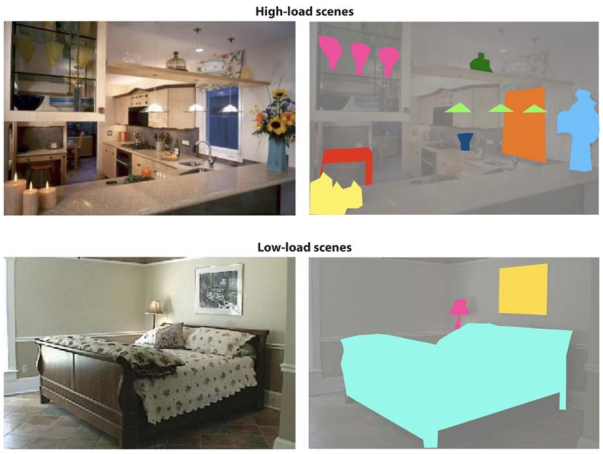

Fig. 2. High-load versus low-load scene stimuli. Examples of high-load (top) and low-load (bottom) scenes as participants saw them (left) and as classified according to the object load (right). During the encoding phase, in the scanner, participants indicated with a button press whether the scene was "indoor" or "outdoor." During the retrieval phase, outside the scanner, participants indicated whether the scene was "old" (i.e., previously seen) or "new" (i.e., not previously seen).

low-load categories were equally distributed among old and new scenes in both the encoding and retrieval phases (i.e., 50% of stimuli in each category), and we analyzed "object load" as a categorical variable. Note that this approach has already proved useful in revealing meaningful age effects on memory recognition in developmental samples (e.g., Chai et al., 2010; Yin et al., 2020). Participants were not made aware of the scene load variation.

Neuropsychological assessment. All participants underwent comprehensive neuropsychological testing to ensure that no objective cognitive deficit was present. Neuropsychological tests included the Wechsler Abbreviated Scale of Intelligence II (Wechsler, 2011) to obtain participants' age-normed IQ scores; the Rey Auditory Verbal Learning Task (Rey, 1958) and the adult battery of the Wechsler Memory Scale-IV (Wechsler, 2009) to assess memory; the Trail Making Test (TMT; Reitan & Wolfson, 1986) A and the digit symbol-coding subtest of the Wechsler Adult Intelligence Scale III (Wechsler, 1997) to assess attention; the Stroop test (Stroop, 1935) and the TMT-B to assess executive functions; and the semantic fluency task (animals and occupations) to assess language. To quantify participants' severity of memory complaints, we used the frequency-of-forgetting subscale of the Memory Functioning Questionnaire (Gilewski, Zelinski, & Schaie, 1990) and inverted the scores to obtain a more intuitive interpretation of them (i.e., higher scores indicate more complaints). More specifically, for questions 1–5 (i.e., belonging to the General Frequency of Forgetting factor), we inverted each item level response (i.e., $8 - x$) and then calculated the average across the 33 responses so that bigger scores indicate more complaints. Finally, personality traits of neuroticism and conscientiousness (Big Five Inventory; John, Donahue, & Kentle, 1991) and depressive symptoms (Geriatric Depression Scale, GDS; Yesavage et al., 1982) were also assessed because they are common in SCD and likely contributing factors to it (Molinuevo et al., 2017). Because the GDS includes a question on the perception of memory problems (i.e., question 14: "Do you feel you have more problems with memory than most?"), to which this SCD sample is more likely to respond "Yes" (Viviano et al., 2019), we computed the GDS score excluding this question.

Data analysis. Data analysis of behavioral performance during retrieval included testing for differences in each of three memory indices that were computed from participants' behavioral responses following the Two-High-Threshold Model (Snodgrass & Corwin, 1988): Hit rate (H; $\frac{Hits}{OldScenes}$); False-alarm rate (FA; $\frac{FalseAlarms}{NewScenes}$); and Recognition Accuracy ($P_r = H - FA$). "Hits" denote the number of old scenes correctly identified as old and "misses" the number of old scenes incorrectly identified as new; "false alarms" denote the number of new scenes incorrectly identified as old and "correct rejections" the number of new scenes correctly identified as new. To calculate these scores, all responses were included independently of the confidence rating associated with them ("sure" or "unsure")[3]. However, to obtain a measure of guessing (which, according to the Two-High-Threshold Model, occurs when the observer is in an "uncertain" state), we additionally calculated and analyzed the bias index B_r

3 Although in the previous study we only included "sure" responses, in the present study, we used all responses because of the stimuli reduction due to load categories.

(see Snodgrass & Corwin, 1988): If an observer fails to recognize an item as new, which occurs with probability $1 - P_r$, she/he guesses (when uncertain) that it is "old" with probability B_r. Accordingly, the false-alarm rate is $FA = (1 - P_r)B_r$, and solving for B_r yields $B_r = \frac{FA}{(1-P_r)} = \frac{FA}{(1-(H-FA))}$. Values of $B_r > 0.5$ are indicative of a liberal bias (a tendency to accept a high rate of false alarms), and values <0.5 are indicative of a conservative bias (a tendency to minimize false alarms). To allow comparison, we additionally computed (and provide) the signal detection theory (SDT) sensitivity index d' and the criterion index C, though we performed the main analyses on the indices derived from the Two-High-Threshold Model (see next paragraph).

We computed the three discrimination indices separately for high-load and low-load scenes. The three recognition-memory indices and the bias index were then examined in separate mixed-model analyses of variance (ANOVA), with Group (SCD vs. CON) as between-subject factor and Load (high vs. low) as within-subject factor. Interactions were examined further with one-way ANOVAs at the relevant factor levels. Results were considered significant if $p < .05$. Analyses were conducted using R 3.6.0 (R Core Team, 2019; https://R-project.org/). The anonymized data, codebook, and analysis scripts on which the present results are based can be accessed at [https://osf.io/xsuy7/].

Functional MRI Data

Data preprocessing and analysis. Two-hundred seventy-six volumes (repetition time, 2,200 ms; echo time, 30 ms; field of view, 220 mm; 37 slices; voxel size, 2.8 mm isotropic) of the blood oxygenation level-dependent (BOLD)-fMRI signal per participant were preprocessed and analyzed using the FMRIB's Software Library (FSL; Jenkinson, Beckmann, Behrens, Woolrich, & Smith, 2012) v.6.0 (https://fsl.fmrib.ox.ac.uk/fsl/). Preprocessing included discarding the first five functional volumes; non-brain tissue removal from functional and structural images (BET; Smith, 2002); motion correction (MCFLIRT; Jenkinson, Bannister, Brady, & Smith, 2002); spatial smoothing with a Gaussian kernel of 4.0 mm full-width-at-half-maximum; high-pass temporal filtering with a cut-off of 100 s; and linear co-registration with the high-resolution anatomical image (FLIRT; Jenkinson et al., 2002). Prior to statistical analyses, the preprocessed images were inspected for quality assurance, which included visual inspection of each participant's image for adequate coregistration with the anatomical image and possible imaging artifacts, as well as the identification of data sets with high motion, defined as maximum absolute displacement >1.5 times the voxel size (i.e., 4.2 mm) accompanied by a mean absolute displacement greater than half a voxel (i.e., 1.4 mm)[4]. Whole-brain first-level BOLD-fMRI data analyses were conducted using FEAT (fMRI Expert Analysis Tool) v.6.0. For each participant, the time-series statistical analysis was carried out using FILM with local autocorrelation correction (Woolrich, Ripley, Brady, & Smith, 2001). Events corresponding to all scenes were included in the analysis independently of whether or not they were subsequently recognized in the memory test, with one regressor for each load category (high-load and low-load event trials were defined according to the scenes' object-load categorization described in *Scene Memory Task*). These events were convolved with a canonical double-gamma hemodynamic response function. Null events were not modeled separately but served as a baseline. The six motion parameters estimated from MCFLIRT, their temporal derivatives, and the squares of all these were further added to the model as confound variables. A "high-load > low-load" contrast (i.e., the high-load parameter minus low-load parameter estimate) was computed in the first-level analysis, and independently of statistical significance at the individual or group levels (e.g., Kriegeskorte, Simmons, Bellgowan, & Baker, 2009), its values within a predefined region of interest (ROI, see next paragraph) were later extracted for statistical inference (i.e., outside of the image space). The inverse contrast (i.e., "low-load > high-load") was also calculated, though only for completeness, in the complementary, voxelwise whole-brain analysis (see Supplementary Material 2).

In accordance with our study rationale and hypotheses, we extracted each participant's mean BOLD signal change from each of two ROIs relevant for the visual processing of scenes, using FSL's Featquery tool (see *ROI Definition*): (a) in response to high-load and low-load scenes separately (i.e., from each of the two parameter estimate images, Fig. 3) and (b) for the "high-load > low-load" contrast (i.e., from the contrast parameter estimate image, Fig. 4). Based on the extracted values for each individual, we compared the effects on BOLD signal change (as defined in point "a") of Group (between-subject factor), and ROI and Load (within-subject factors), through mixed-model ANOVAs. Next, we examined whether BOLD signal change (as defined in point "b") and Group predict Recognition Accuracy, through linear regression. Finally, we explored whether H, FA, and/or their interaction with Group predict BOLD signal change (as defined in point "b") in PPA, through linear regression. Linear contrasts were used to compare between regression estimates. Results were considered significant if $p < .05$.

ROI definition. One of our main goals was to investigate whether and how the perceptual detail contained in scenes modulates memory encoding in older adults with SCD. Thus, we specifically focused on a brain region relevant for scene processing

4 Of note, SCD and CON did not differ in the degree of head motion in the scanner during scene encoding (maximum absolute displacement: 1.63 vs. 1.75 mm for SCD vs. CON, $t(34.9) = -0.33$, $p = .741$; and mean absolute displacement: 0.53 vs. 0.48 mm for SCD vs. CON, $t(33.7) = 0.64$, $p = .526$).

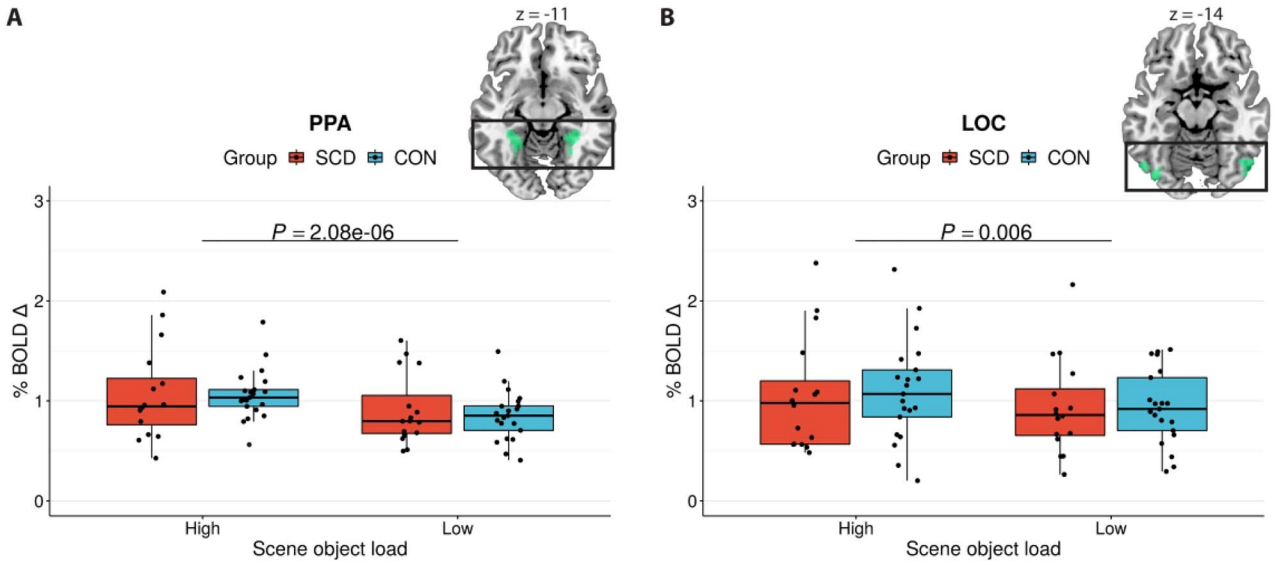

Fig. 3. Percent blood oxygenation level-dependent (BOLD) signal change to high-load and low-load scenes. Boxplots showing the percent BOLD signal change (% BOLD Δ, obtained from each ROI in response to high-load and low-load scenes separately) of the (A) parahippocampal place area (PPA) and (B) lateral occipital complex (LOC) ROIs (shown in green on the top right of each panel) for older adults with ("SCD," in red) and without ("CON," in blue) SCD. Both ROIs exhibited higher activation for high-load versus low-load scenes, but this did not differ between SCD and CON. The *p*-values on each plot correspond to the significant main effect of object load assessed in follow-up mixed analyses of variance (ANOVA) for PPA [$F(1, 35) = 32.226$] and LOC [$F(1, 35) = 8.631$] separately. The horizontal line of each box corresponds to the median, the lower and upper hinges correspond to the first and third quartiles, respectively, and the black dots to the individual data points. SCD = subjective cognitive decline; CON = controls.

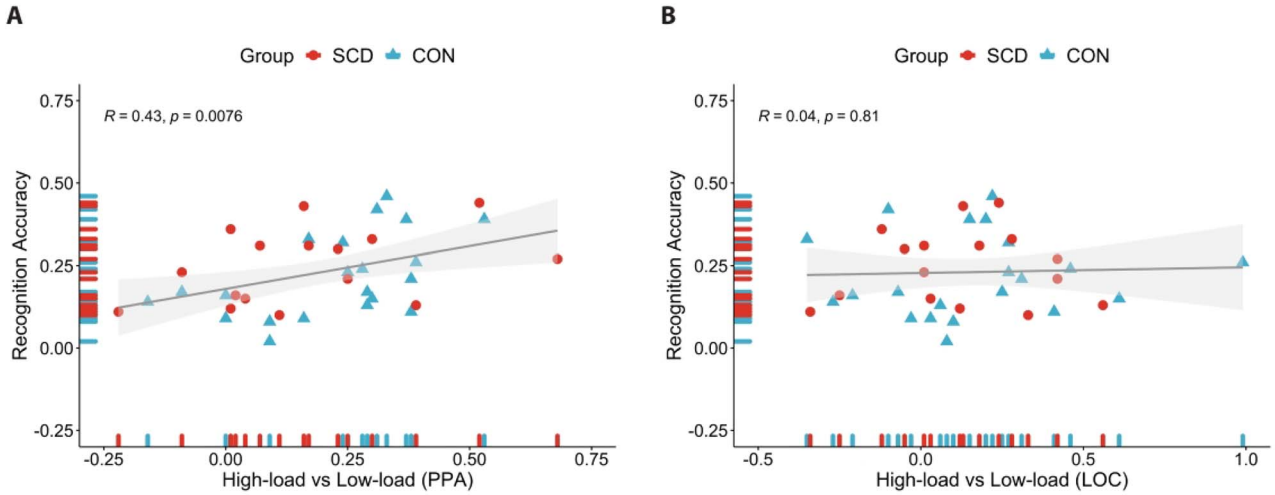

Fig. 4. High-load > low-load contrast parameter estimates and memory performance. Correlations between PPA (A) and LOC (B) activation to high-load versus low-load scenes and recognition accuracy across participants with ("SCD," red circles) and without ("CON," blue triangles) SCD. The markers on the *x* and *y* axes indicate the position of individual data points (SCD in red and CON in blue) for each variable's distribution. The shaded area around the regression line represents the 95% confidence interval. SCD = subjective cognitive decline; CON = controls.

that has proved relevant for revealing age effects on memory for scenes (i.e., PPA; Koen et al., 2019). Additionally, we used another region (LOC) as a control region. Hence, we generated putative PPA and LOC masks based on independently defined information: We first obtained functional masks of brain areas related to "place" (PPA) and "object recognition" (LOC) based on two Neurosynth (https://neurosynth.org/; Yarkoni, Poldrack, Nichols, Van Essen, & Wager, 2011) meta-analyses, and then we constrained these masks to anatomical areas composing PPA and LOC (see Supplementary Material 1.3 for details).

Table 2. Neuropsychological data of the study sample

	SCD ($n = 16$) Mean ± *SD*	CON ($n = 21$) Mean ± *SD*	*t*-value (*p*-value)
Memory complaints			
MFQ - Frequency-of-forgetting factor	153.53 ± 29.82[a]	170.62 ± 26.27	**−1.78 (.043*)**
MFQ - Frequency-of-forgetting factor (inverted score)**	3.34 ± .90[a]	2.83 ± 0.80	**1.75 (.045*)**
Intelligence			
Wechsler Abbreviated Scale of Intelligence II - Full-scale IQ	100.56 ± 13.35	97.43 ± 9.91	.79 (.437)
Attention			
TMT-A (s)	46.20 ± 19.96[a]	52.57 ± 26.90	−.81 (.421)
Digit symbol substitution	36.87 ± 6.19[a]	37.33 ± 12.11	−.15 (.881)
Executive functions			
Stroop interference (ratio)	2.11 ± .43[a]	1.88 ± 0.26	1.76 (.092)
TMT-B (s)	137.88 ± 94.70[a]	133.14 ± 96.51	.15 (.884)
Memory			
WMS Auditory Memory Index	0.47 ± .11[a]	0.46 ± 0.14	.26 (.797)
WMS Visual Memory Index	0.55 ± .11[a]	0.53 ± 0.09	.53 (.602)
WMS Visual Working Memory Index	0.39 ± .12[a]	0.39 ± 0.14	−.05 (.960)
WMS Delayed Memory Index	0.47 ± .10[a]	0.46 ± 0.12	.44 (.660)
WMS Immediate Memory Index	0.55 ± .08[a]	0.53 ± 0.09	.68 (.499)
Rey Auditory Learning total score	46.88 ± 7.24	44.71 ± 8.57	.83 (.412)
Rey Auditory Learning retention score	2.38 ± 2.22	1.95 ± 2.73	.52 (.607)
Language			
Semantic verbal fluency	34.13 ± 7.29[a]	36.86 ± 6.35	−1.17 (.254)
Questionnaires			
Big Five Inventory—Neuroticism	16.80 ± 5.82[a]	16.43 ± 5.90	.19 (.852)
Big Five Inventory—Conscientiousness	37.87 ± 4.24[a]	37.38 ± 5.86	.29 (.775)
Geriatric Depression Scale***	4.38 ± 3.79	2.05 ± 2.67	**2.09 (.047)**

Note. CON = controls; MFQ = Memory Functioning Questionnaire; SCD = subjective cognitive decline; TMT = Trail Making Test; WMS = Wechsler Memory Scale. Boldface indicates a significant difference between the groups.

[a]One missing data point.

*One-tailed based on the alternative hypothesis that SCD > CON, although note that SCD definition and group assignment was *not* based on this frequency score, but on the separate question of whether participants noticed decline and their memory *and* felt worrisome about that decline.

**This score was calculated by inverting each item-level response ($8 - x$) and calculating the average across all responses.

***This score does not include the response to the memory-related question (question 14), in which none of the CON participants but seven of the SCD participants responded "yes" ($t_{15} = -3.42$, p-value = .004; $\bar{x}$ SCD = 0.44; $\bar{x}$ CON = 0.00).

Results

Demographics, and Neuropsychological and Behavioral Performance

SCD and CON did not significantly differ in any demographic (p-values >.073, Table 1) or neuropsychological (p-values >.091, Table 2) variable, except for the frequency of memory complaints (i.e., MFQ frequency-of-forgetting factor; $p = .045$, one-tailed), the proportion of participants who sought medical help owing to complaints and were still regarded as healthy (75% in SCD vs. 0% in CON, $p < .001$), and depressive symptoms ($p = .047$). These results are in line with our expectations and the core definition of SCD, thus corroborating the current group assignment. Even though we found a difference in depressive symptoms, the SCD group mean is still well in the subclinical range for depression, and the results were essentially the same when depressive symptoms were controlled for (data not shown).

Regarding behavioral performance during scene retrieval, SCD and CON did not significantly differ in overall *H*, *FA*, or Recognition Accuracy (p-values >.111; Table 3), or in the bias index B_r ($p = .165$). SCD and CON did also not differ in the equivalent SDT indices: sensitivity d' and criterion *C* (both p-values >.160; Table 3).

Effect of Object Load and SCD on Brain Activation During Memory Encoding

There was a significant main effect of Load [$F(1, 35) = 19.46$, $p = 9.36\text{e-}5$, $\eta_p^2 = 0.36$], with activation being overall higher for high-load versus low-load scenes in both ROIs (Fig. 3). There were no significant main effects of Group [$F(1, 35) = .001$, $p = .971$, $\eta_p^2 = 3.8\text{e-}5$] or ROI [$F(1, 35) = 0.316$, $p = .578$, $\eta_p^2 = .009$], nor were there any two- (p-values >.229) or three-way

Table 3. Memory indices of scene recognition

	SCD ($n = 16$) Mean ± *SD*	CON ($n = 21$) Mean ± *SD*	*t*-value (*p*-value)
Overall hit rate	0.64 ± 0.20	0.54 ± 0.18	1.64 (.112)
Hit rate (high confidence)	0.53 ± 0.20	0.46 ± 0.18	1.05 (.303)
Overall false-alarm rate	0.40 ± 0.22	0.32 ± 0.17	1.14 (.267)
False-alarm rate (high confidence)	0.11 ± 0.11	0.06 ± 0.08	1.40 (.172)
Overall recognition accuracy P_r	0.25 ± 0.11	0.22 ± 0.13	.77 (.444)
Recognition accuracy (high confidence)	0.42 ± 0.23	0.40 ± 0.20	.27 (.788)
Sensitivity index d'	0.74 ± 0.34	0.60 ± 0.34	1.22 (.231)
Bias index B_r	0.52 ± 0.26	0.41 ± 0.20	1.43 (.165)
Criterion *C*	0.06 ± 0.61	0.20 ± 0.48	−1.44 (.161)

Note. CON = controls; SCD = subjective cognitive decline.

($p = .887$) interactions. *Post hoc*, we observed PPA activation to correlate negatively with the MFQ frequency-of-forgetting score (a potential proxy measure of SCD) across all participants (high-load scenes: $r_{36} = -.24$, $p = .166$; low-load scenes: $r_{36} = -.26$, $p = .123$); while these correlations are in the expected direction (i.e., lower activation for higher frequency of forgetting), they did not reach significance. The corresponding correlations for LOC were around zero ($r_{36} = .02$, $p = .901$ and $r_{36} = .07$, $p = .689$, for high-load and low-load scenes, respectively).

Complementing our ROI-based approach, we examined, in an exploratory whole-brain, voxelwise analysis, whether SCD did differ from CON in other brain regions than our theoretically motivated, *a priori* ROIs (see details of this analysis, including statistical results in Supplementary Material 2). High-load scenes were associated with higher activation than low-load scenes in occipital (V1, V2, and lateral occipital cortex) and medial parietal (precuneus) cortices across all participants. Importantly, though, SCD did not differ from CON in high-load > low-load whole-brain activation.

Relationship Between Brain Activation During Encoding and Overall Memory Performance During Retrieval

We found that higher "high-load > low-load" (i.e., perceptual detail) BOLD signal change in PPA was predictive of higher Recognition Accuracy ($\beta = .57$, standard error, $SE = 0.16$, $p = .002$, 95% confidence interval [CI] [0.25, 0.90]; Fig. 4A). For LOC, the prediction exhibited a nonsignificant trend ($\beta = -.18$, $SE = .09$, $p = .064$, 95% CI [−0.37, −.003]; Fig. 4B) in the *opposite* direction (i.e., higher BOLD signal change for high-load > low-load predicting *lower* Recognition Accuracy). Neither Group ($\beta = .09$, $SE = .05$, 95% CI [−.004, 0.19], $p = .069$) nor any of the ROI × Group interactions (*p*-values >.485) were significant. Linear contrasts of each ROI's coefficients—which directly compare the magnitude of each ROI's prediction of Recognition Accuracy—determined their difference to be statistically significant ($z = 3.20$, $p = .001$).

Finally, we found that PPA's "high-load > low-load" activation was significantly more strongly associated with the false-alarm rates (*FA*: $\beta = -.87$, $SE = 0.37$, $p = .026$, 95% CI [−1.59, −0.14]) than with the hit rates (*H*: $\beta = .66$, $SE = 0.35$, $p = .065$, 95% CI [−.02, 1.35]) ($z = -2.82$, $p = .023$). Neither the hit rates nor the false-alarm rates' interaction with Group was significant (both *p*-values >.820).

Effect of Object Load and SCD on Behavioral Performance During Memory Retrieval

We expected a reduced object-load effect for SCD during memory retrieval, that is, a larger load effect for the CON group. The results are depicted in Fig. 5. The hypothesized Load × Group interaction was significant for *FA* [$F(1, 35) = 6.15$, $p = .018$, $\eta_p^2 = 0.15$; Fig. 5B], but neither for *H* nor overall Recognition Accuracy (both *p*-values >.316). Follow-up one-way ANOVAs, performed separately per Group, revealed that for CON [$F(1, 20) = 12.3$, $p = .002$, $\eta_p^2 = 0.38$], but not for SCD [$F(1, 15) = .02$, $p = .879$, $\eta_p^2 = .002$], the difference in *FA* between high-load and low-load scenes was statistically significant: CON participants committed fewer false alarms with high-load scenes (Table 4). The main effect of Load was significant across groups for *FA* [$F(1, 35) = 5.09$, $p = .030$, $\eta_p^2 = 0.13$] and Recognition Accuracy [$F(1, 35) = 8.04$, $p = .008$, $\eta_p^2 = 0.19$; Fig. 5C], with better performance for high-load than for low-load scenes. No further significant effects were observed for *H* (*p*-values >.108), *FA* ($p = .251$), or Recognition Accuracy (*p*-values >.250).

Finally, concerning the bias index B_r, there was a significant Load × Group interaction [$F(1, 35) = 4.93$, $p = .033$, $\eta_p^2 = 0.12$], but no significant main effects (*p*-values >.123), the latter being indicative of little overall difference in bias between the Load and, respectively, Group levels. Follow-up one-way ANOVAs showed that the interaction effect was largely explained by a

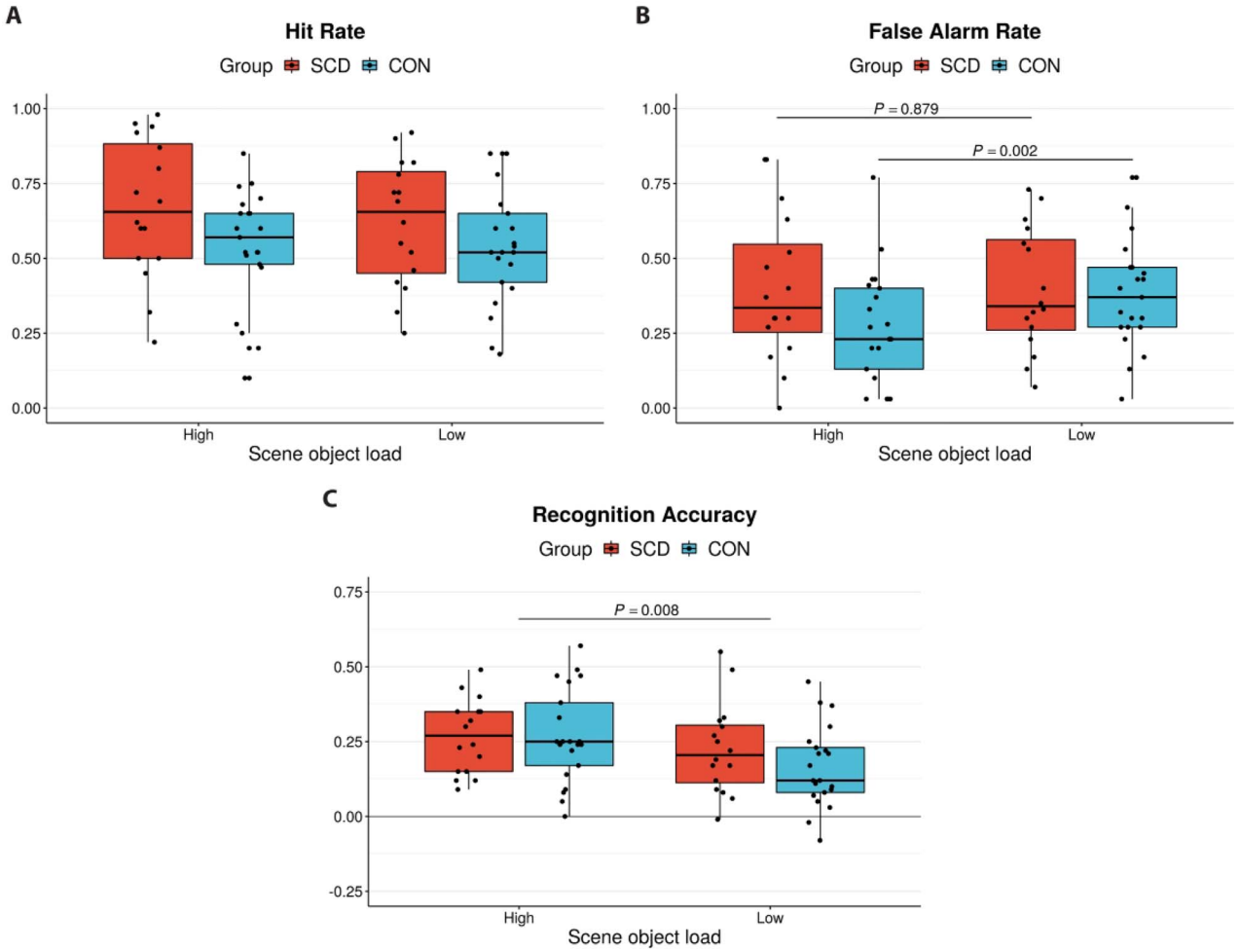

Fig. 5. Effect of scenes' object load on scene memory recognition. Behavioral results for each memory index (hit rate, A; false-alarm rate, B; recognition accuracy, C), separately for each group (with and without subjective cognitive decline, SCD and CON, respectively) and object load within scenes (high and low). *P*-values in (B) resulted from a one-way analysis of variance (ANOVA) within each group. The *p*-value in (C) corresponds to the main effect of Load in the mixed ANOVA. All *y*-axes values show ratios. The horizontal line of each box corresponds to the median, the lower and upper hinges correspond to the first and third quartiles, respectively, and the dots to the individual data points. CON = controls.

significant main effect of Load on the bias index for CON [$F(1, 20) = 6.20$, $p = .022$, $\eta_p^2 = .05$], but not for SCD ($F(1, 15) = 0.53$, $p = .478$, $\eta_p^2 = .003$): CON participants responded more conservatively (minimizing false alarms) to high-load (0.36 ± 0.22) than to low-load scenes (0.45 ± 0.21). In contrast, SCD participants did not exhibit increased caution with high-load displays (0.54 ± 0.30 vs. 0.51 ± 0.24). Differential bias indices were also manifest in a cross-group comparison for high-load scenes (CON vs. SCD: 0.36 vs. 0.54, $F(1, 35) = 4.39$, $p = .043$, $\eta_p^2 = 0.11$), but not for low-load scenes (0.45 vs. 0.51, $F = 0.60$). And only CON participants' responses to high-load scenes clearly deviated from 0.5 ($t(20) = -2.89$, $p = .009$), but not their responses to low-load scenes ($p = .329$) or SCD participants' responses to high-load ($p = .602$) or low-load scenes ($p = .847$).

Discussion

We investigated whether older adults with SCD benefit less from perceptual detail during scene encoding and/or retrieval compared to older adults without SCD (CON). Our main finding was that, during retrieval, older adults with SCD showed no reduction in false-alarm rates for scenes with more versus less perceptual detail, in contrast to the benefit exhibited by the CON group and seemingly at variance with the higher overall recognition accuracy for scenes containing more detail. This attenuated effect of perceptual detail on retrieval performance in SCD suggests that older adults with SCD might not recall *old* scenes with high perceptual precision, making it hard for them to correctly reject *new* scenes, especially those with more detail. Thus, at least

Table 4. Memory indices of scene recognition per Load level

	SCD ($n = 16$) Mean ± *SD*	CON ($n = 21$) Mean ± *SD*	*t*-value (*p*-value)
High-load scenes			
Hit rate	0.67 ± 0.23	0.54 ± 0.19	1.81 (.081)
False-alarm rate	0.40 ± 0.25	0.27 ± 0.19	1.74 (.092)
Recognition accuracy P_r	0.27 ± 0.12	0.27 ± 0.16	.0006 (.999)
Sensitivity index *d'*	0.87 ± 0.41	0.78 ± 0.50	.62 (.539)
Bias index B_r	0.54 ± 0.30	0.36 ± 0.22	2.01 (.055)
Criterion *C*	−0.12 ± 0.72	0.30 ± 0.53	−1.96 (.061)
Low-load scenes			
Hit rate	0.62 ± 0.21	0.54 ± 0.20	1.18 (.248)
False-alarm rate	0.39 ± 0.21	0.38 ± 0.18	.297 (.769)
Recognition accuracy P_r	0.22 ± 0.15	0.16 ± 0.14	1.25 (.219)
Sensitivity index *d'*	0.63 ± 0.41	0.45 ± 0.36	1.36 (.185)
Bias index B_r	0.51 ± 0.24	0.45 ± 0.21	.76 (.456)
Criterion *C*	−0.01 ± 0.56	0.12 ± 0.49	−.79 (.437)

Note. CON = controls; SCD = subjective cognitive decline.

some of the subjectively perceived memory problems in older adults with SCD may refer to a reduced benefit from perceptual detail during retrieval, impacting individuals' ability to determine that newly presented scenes are actually new, rather than previously seen. We found that higher activation of the PPA during the encoding of scenes with more versus less perceptual detail was associated with higher recognition accuracy, though across all participants—indicating that encoding of perceptual detail aids memory retrieval overall, and this is not different in older adults with SCD. We also found a stronger relation of PPA activation to perceptual detail during encoding with the false-alarm rates (as compared to the hit rates) in the subsequent memory test, though again also across all participants. This indicates that the retrieval benefit associated with the processing of perceptual detail in PPA during encoding plays a crucial role later on for telling apart old (previously seen) from new scenes, and this is again not different in older adults with SCD. In light of the, by definition, adequate neuropsychological performance of older adults with SCD, their apparent adequate encoding of perceptual details in PPA, and their failure to adapt their response criteria in accordance with the object load of to-be-judged scenes, our main behavioral finding would, mechanistically, speak to a "lower-resolution *retrieval*" in SCD.

Lower-Resolution Retrieval in Older Adults With SCD

Our main, behavioral finding is that older adults with SCD, compared to CON, exhibited a reduced high-load scene "advantage" during retrieval in distinguishing new from old scenes, evidenced by an increased false-alarm rate and absent "adjustment" of their response criteria to a more cautious setting with high-load scenes. False recognition is elevated in older compared to younger adults and can result from both reduced strategic retrieval (i.e., first recalling the details of a target and then detecting its difference from a lure) and reduced availability of object details (Trelle, Henson, Green, & Simons, 2017). In older adults at risk of mild cognitive impairment, recognition memory is characterized less by forgetting than by falsely accepting "new" objects as "old" (Yeung, Ryan, Cowell, & Barense, 2013). In the present study, older adults with SCD derived less advantage from high-load scenes (with a higher amount of detail) to reduce false recognition. Accordingly, individuals with SCD might have reduced availability of, or access to, the perceptual detail information (i.e., "lower-resolution retrieval") that would otherwise help them differentiate new from old material. Given this, rather than relying on perceptual detail, they might rely more on an incomplete or partial version, providing the "gist," of the scene—a "low-cost," but error-prone solution to decide whether a given scene is new versus old (see also Evans & Baddeley, 2018). To elaborate, when only a partial memory can be retrieved, but the to-be-judged scene is realized to depict, say, a kitchen, then recalling that a kitchen was seen in the preceding learning phase may make an SCD participant more willing to issue a "yes" response, thus especially increasing the false-alarm rate; such false alarms would be avoidable if the scene could be recalled in sufficient detail to rule out that, while it fits the "kitchen" gist, it does not exactly match the kitchen seen before. A similar shift in strategy has been previously described in older versus younger adults (Devitt & Schacter, 2016; Koutstaal, 2003). An intriguing question arising from this shift is whether it reflects subtle decreases in other functions involving frontal brain systems (see, e.g., Memel & Ryan, 2017) that could modulate how the to-be-judged scene is perceived during retrieval (e.g., processing speed, working memory, or top-down control; e.g., Finke, Myers, Bublak, & Sorg, 2013). A systematic analysis of the role of these functions in SCD might help answer this question.

Lower-resolution retrieval would also explain why older adults with SCD, unlike those without SCD, do not adjust their response criteria in line with the presented scene's perceptual detail. When a to-be-judged scene is high in perceptual detail, this would increase partial matches with scenes (of the same category) seen before—potentially increasing the false-alarm rate. In this situation, more conservative responding would help mitigate the acceptance of "false" memories. The finding that SCD individuals tend not to guard against this possibility (by appropriately adjusting their response criteria) might reflect a failure of metacognition, that is, lacking acknowledgment of the potential downside of false recognitions. Alternatively, being concerned and complaining about "forgetting," they might tend to maximize hits (by responding "yes") in a test situation to prove good memory function, deliberately accepting (rather than ignoring) the increased rate of false recognitions as a necessary side effect of this response strategy.

The high-load scene advantage, which was expressed more prominently in reduced false-alarm rates, suggests that the availability of perceptual detail is particularly important under conditions that require correct rejection of new information (i.e., when presented with a new item in the memory test that needs to be established as "new," rather than "old"). Overall, these findings suggest that the sensitivity to detect objective memory deficits in SCD in neuropsychological assessment might be increased by employing test material that is high in perceptual detail and by focusing on false recognitions in the memory test; potentially also by including (e.g., visuospatial working memory) tests that require the maintenance and active manipulation of detailed visual information (e.g., the spatial addition test of the WMS).

Scene Perceptual Detail Encoding in PPA Is Related to More Accurate Recognition and Appears More Relevant for Distinguishing New Scenes

Higher PPA activation during exposure to scenes with more perceptual detail predicted more accurate recognition in all participants, relative to scenes with less perceptual detail (in contrast with LOC; see Supplementary Material 3)—in agreement with previous studies comparing scene versus non-scene material (e.g., Koen et al., 2019) or examining scene complexity in developmental samples (e.g., Chai et al., 2010). This result is in line with a role of the parahippocampal cortex in supporting contextual associations (i.e., spatial and conceptual links between items; Aminoff, Kveraga, & Bar, 2013), as scenes with more perceptual detail would inherently contain more context information. Other, non-scene-specific brain regions affected in aging (e.g., frontal cortices) might also play a role in correctly recognizing scenes varying in perceptual detail. Accordingly, future studies could analyze the role of age-sensitive frontal functions (e.g., processing speed, working memory, or top-down control) in SCD to help elucidate the degree to which the encoding of scene perceptual detail involves (e.g., attentional) control processes important for successful recognition later on. The false-alarm rate was more strongly associated with PPA activation than the hit rate. Context plays a greater role for recognition decisions based on recollection (involving the retrieval of details) as compared to familiarity judgments (relying on subjective memory strength) (Diana, Yonelinas, & Ranganath, 2007). Thus, the differential strength of the association between PPA activation and the false-alarm and, respectively, the hit rates would be indicative of the role of recollective, as compared to familiarity-based, processes for deciding that a new scene is actually new, rather than seen earlier on.

A previous study (Hayes et al., 2017)—which included a sample that partly overlaps with the present one, but whose focus was on subsequent memory—found decreased brain activations in occipital, lateral and medial parietal, and ventromedial frontal cortices to later correctly remembered scenes in SCD individuals, even though their behavioral memory performance was comparable to that of CON participants. In the light of the current results, this disparity between brain activation during encoding and retrieval performance indicates that SCD individuals rely on partial versions of scenes (i.e., lower-resolution retrieval). These partial versions might be sufficient for the recognition of old material, but not for the rejection of new material, especially if the latter is high in perceptual detail.

Perceptual Encoding of Scene Detail in PPA Does Not Appear to Differ for SCD

Mean activation in the PPA to high-load versus low-load scenes did not differ between older adults with and without SCD, suggesting that PPA's neural differentiation may not be affected in SCD beyond the typical age-related reduction (Park et al., 2004). However, this remains to be confirmed in future studies including larger samples, a larger stimulus set, or systematic stimulus variations (e.g., by using computer-rendered scenes, permitting the scene content to be readily manipulated). While the present study focused on PPA because of our particular interest in the *visual* processing of scene details and its effect on memory in SCD, examining specifically the anterior/posterior division of PPA (e.g., Baldassano, Esteva, Fei-Fei, & Beck, 2016) or other well-defined scene-relevant regions (e.g., the occipital place area or the retrosplenial complex) might prove fruitful in the future.

Patients with mild cognitive impairment and Alzheimer's disease may exhibit deficits in visual contrast sensitivity (Risacher et al., 2013) or simultaneous object perception (Ruiz-Rizzo et al., 2017), which are associated with reduced visual memory performance. Thus, PPA's activation to scenes' perceptual detail may start to decrease when more advanced neurodegeneration or objective memory deficits are present. Taking into account the duration of the SCD status (see Viviano & Damoiseaux, 2020) could help address that possibility, as older adults with SCD may be too early in the trajectory of cognitive impairment to exhibit that effect. In this regard, longitudinal studies of changes in brain activation to scenes' perceptual detail or in the active retrieval of scenes with high detail could help us identify the trajectories of those older adults with SCD who will eventually convert to mild cognitive impairment and dementia.

In interpreting our findings, some limitations should be taken into account. First, our sample mostly included female participants, which limits generalization of our results to male older adults. Second, our single-run fMRI design, especially suited for older adults, did not lend itself to more sensitive, multivariate approaches to fMRI data analysis (see, e.g., MacEvoy & Epstein, 2011), which might reveal multivoxel pattern differences in perceptual detail encoding between groups. Another possible reason for the limited sensitivity of our fMRI approach relates to the SCD group definition (especially in the context of a community-based sample) being based on a single question regarding participants' (subjective) concern about their overall memory (as opposed to using some cut-off point on, e.g., the MFQ or a similar questionnaire). Arguably, though, this definition is of clinical value because these are the individuals who are more likely to express a need for, and/or actually seek, medical help. The latter was the case for the majority of our SCD participants, but for none of the CON participants. Nevertheless, although our null univariate finding still corresponds well with the, by definition, normal health status and cognition of older adults with SCD, future studies could refine the definition of SCD by developing (or including recently recommended) quantitative measures of the SCD experience, including specific questions about cognitive processes other than memory (see, e.g., Molinuevo et al., 2017; Rabin et al., 2015). While acknowledging our study's limitations and sample size, and the inherent heterogeneity and subjectivity of SCD, we believe our results can inform future studies by suggesting a possible mechanism behind SCD's perceived decline, namely lower-resolution retrieval. This possibility not only points to examining brain activity during memory retrieval tasks, but especially also tasks assessing attention, executive functioning, or general visual processing in SCD.

To conclude, older adults with SCD appear to benefit from perceptual detail encoding in PPA for overall memory performance similarly to older adults without SCD. However, during memory retrieval, new stimuli of high perceptual detail do not provide a performance "advantage" in older adults with SCD comparable to that of older adults without SCD. Together, these results suggest that perceived memory problems in older adults with SCD may refer to a reduced benefit from perceptual detail during retrieval and that both future research and the clinical neuropsychological assessment of typically performing older adults with cognitive complaints could focus on visual material of high perceptual detail and/or false recognition to help detect objective memory problems in SCD.

Supplementary Material

Supplementary material is available at *Archives of Clinical Neuropsychology* online.

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Conflict of Interest

The authors declare no conflicts of interest.

Author Contributions

A.L.R.-R. and J.S.D. conceived the study. A.L.R.-R. preprocessed and analyzed the data. A.L.R.-R., H.J.M., and J.S.D. interpreted the results. A.L.R.-R. drafted the manuscript. J.S.D., P.J.P., K.F., and H.J.M. critically reviewed the manuscript and provided constructive theoretical feedback. All authors approved the final version of the manuscript for submission.

References

Aminoff, E. M., Kveraga, K., & Bar, M. (2013). The role of the parahippocampal cortex in cognition. *Trends in Cognitive Sciences*, *17*(*8*), 379–390. 10.1016/j.tics.2013.06.009.

Baldassano, C., Esteva, A., Fei-Fei, L., & Beck, D. M. (2016). Two distinct scene-processing networks connecting vision and memory. *eNeuro*, *3*(*5*), ENEURO.0178–ENEU16.2016. 10.1523/ENEURO.0178-16.2016.

Bar, M., Aminoff, E., & Schacter, D. L. (2008). Scenes unseen: The parahippocampal cortex intrinsically subserves contextual associations, not scenes or places per se. *Journal of Neuroscience*, *28*(*34*), 8539–8544. 10.1523/JNEUROSCI.0987-08.2008.

Brooks, B. L., Iverson, G. L., Holdnack, J. A., & Feldman, H. H. (2008). Potential for misclassification of mild cognitive impairment: A study of memory scores on the Wechsler Memory Scale-III in healthy older adults. *Journal of the International Neuropsychological Society*, *14*(*3*), 463–478. 10.1017/S1355617708080521.

Chai, X. J., Ofen, N., Jacobs, L. F., & Gabrieli, J. D. E. (2010). Scene complexity: Influence on perception, memory, and development in the medial temporal lobe. *Frontiers in Human Neuroscience*, *4*, 1–10. 10.3389/fnhum.2010.00021.

Contreras, J. A., Goñi, J., Risacher, S. L., Amico, E., Yoder, K., Dzemidzic, M. et al. (2017). Cognitive complaints in older adults at risk for Alzheimer's disease are associated with altered resting-state networks. *Alzheimer's & Dementia: Diagnosis, Assessment & Disease Monitoring*, *6*(*1*), 40–49. 10.1016/j.dadm.2016.12.004.

Dennis, N. A., Bowman, C. R., & Peterson, K. M. (2014). Age-related differences in the neural correlates mediating false recollection. *Neurobiology of Aging*, *35*(*2*), 395–407. 10.1016/j.neurobiolaging.2013.08.019.

Devitt, A. L., & Schacter, D. L. (2016). False memories with age: Neural and cognitive underpinnings. *Neuropsychologia*, *91*, 346–359. 10.1016/j.neuropsychologia.2016.08.030.

Diana, R. A., Yonelinas, A. P., & Ranganath, C. (2007). Imaging recollection and familiarity in the medial temporal lobe: A three-component model. *Trends in Cognitive Sciences*, *11*(*9*), 379–386. 10.1016/j.tics.2007.08.001.

Epstein, R. A., & Baker, C. I. (2019). Scene perception in the human brain. *Annual Review of Vision Science*, *5*(*1*), 373–397. 10.1146/annurev-vision-091718-014809.

Epstein, R., & Kanwisher, N. (1998). A cortical representation of the local visual environment. *Nature*, *392*(*6676*), 598–601. 10.1038/33402.

Evans, K. K., & Baddeley, A. (2018). Intention, attention and long-term memory for visual scenes: It all depends on the scenes. *Cognition*, *180*, 24–37. 10.1016/j.cognition.2018.06.022.

Finke, K., Myers, N., Bublak, P., & Sorg, C. (2013). A biased competition account of attention and memory in Alzheimer's disease. *Philosophical Transactions of the Royal Society, B: Biological Sciences*, *368*(*1628*), 20130062. 10.1098/rstb.2013.0062.

Gilewski, M. J., Zelinski, E. M., & Schaie, K. W. (1990). The memory functioning questionnaire for assessment of memory complaints in adulthood and old age. *Psychology and Aging*, *5*(*4*), 482–490. 10.1037/0882-7974.5.4.482.

Golby, A., Silverberg, G., Race, E., Gabrieli, S., O'Shea, J., Knierim, K. et al. (2005). Memory encoding in Alzheimer's disease: An fMRI study of explicit and implicit memory. *Brain*, *128*(*4*), 773–787. 10.1093/brain/awh400.

Grill-Spector, K., Kourtzi, Z., & Kanwisher, N. (2001). The lateral occipital complex and its role in object recognition. *Vision Research*, *41*(*10*), 1409–1422. 10.1016/S0042-6989(01)00073-6.

Güçlütürk, Y., Güçlü, U., van Gerven, M., & van Lier, R. (2018). Representations of naturalistic stimulus complexity in early and associative visual and auditory cortices. *Scientific Reports*, *8*(*1*), 3439. 10.1038/s41598-018-21636-y.

Gutchess, A. H., Welsh, R. C., Hedden, T., Bangert, A., Minear, M., Liu, L. L. et al. (2005). Aging and the neural correlates of successful picture encoding: Frontal activations compensate for decreased medial-temporal activity. *Journal of Cognitive Neuroscience*, *17*(*1*), 84–96. 10.1162/0898929052880048.

Hayes, J. M., Tang, L., Viviano, R. P., van Rooden, S., Ofen, N., & Damoiseaux, J. S. (2017). Subjective memory complaints are associated with brain activation supporting successful memory encoding. *Neurobiology of Aging*, *60*, 71–80. 10.1016/j.neurobiolaging.2017.08.015.

Hohman, T. J., Beason-Held, L. L., Lamar, M., & Resnick, S. M. (2011). Subjective cognitive complaints and longitudinal changes in memory and brain function. *Neuropsychology*, *25*(*1*), 125–130. 10.1037/a0020859.

Jenkinson, M., Bannister, P., Brady, M., & Smith, S. (2002). Improved optimization for the robust and accurate linear registration and motion correction of brain images. *NeuroImage*, *17*(*2*), 825–841. 10.1006/nimg.2002.1132.

Jenkinson, M., Beckmann, C. F., Behrens, T. E. J., Woolrich, M. W., & Smith, S. M. (2012). FSL. *NeuroImage*, *62*(*2*), 782–790. 10.1016/j.neuroimage.2011.09.015.

Jessen, F., Amariglio, R. E., Buckley, R. F., van der Flier, W. M., Han, Y., Molinuevo, J. L. et al. (2020). The characterisation of subjective cognitive decline. *The Lancet Neurology*, *19*(*3*), 271–278. 10.1016/S1474-4422(19)30368-0.

Jessen, F., Amariglio, R. E., van Boxtel, M., Breteler, M., Ceccaldi, M., Chételat, G. et al. (2014a). A conceptual framework for research on subjective cognitive decline in preclinical Alzheimer's disease. *Alzheimer's & Dementia*, *10*(*6*), 844–852. 10.1016/j.jalz.2014.01.001.

Jessen, F., Wolfsgruber, S., Wiese, B., Bickel, H., Mösch, E., Kaduszkiewicz, H. et al. (2014b). AD dementia risk in late MCI, in early MCI, and in subjective memory impairment. *Alzheimer's & Dementia*, *10*(*1*), 76–83. 10.1016/j.jalz.2012.09.017.

John, O. P., Donahue, E. M., & Kentle, R. L. (1991). *The Big Five Inventory—Versions 4a and 54*. University of California, Berkeley; Institute of Personality and Social Research, Berkeley, CA. https://www.ocf.berkeley.edu/~johnlab/bfi.htm

Koen, J. D., Hauck, N., & Rugg, M. D. (2019). The relationship between age, neural differentiation, and memory performance. *Journal of Neuroscience*, *39*(*1*), 149–162. 10.1523/JNEUROSCI.1498-18.2018.

Koppara, A., Wagner, M., Lange, C., Ernst, A., Wiese, B., König, H.-H. et al. (2015). Cognitive performance before and after the onset of subjective cognitive decline in old age. *Alzheimer's & Dementia: Diagnosis, Assessment & Disease Monitoring*, *1*(*2*), 194–205. 10.1016/j.dadm.2015.02.005.

Koutstaal, W. (2003). Older adults encode—But do not always use—Perceptual details: Intentional versus unintentional effects of detail on memory judgments. *Psychological Science*, *14*(*2*), 189–193. 10.1111/1467-9280.01441.

Kriegeskorte, N., Simmons, W. K., Bellgowan, P. S. F., & Baker, C. I. (2009). Circular analysis in systems neuroscience: The dangers of double dipping. *Nature Neuroscience*, *12*(*5*), 535–540. 10.1038/nn.2303.

Loewenstein, D. A., Acevedo, A., Ownby, R., Agron, J., Barker, W. W., Isaacson, R. et al. (2006). Using different memory Cutoffs to assess mild cognitive impairment. *The American Journal of Geriatric Psychiatry*, *14*(*11*), 911–919. 10.1097/01.JGP.0000229651.62137.e2.

MacEvoy, S. P., & Epstein, R. A. (2011). Constructing scenes from objects in human occipitotemporal cortex. *Nature Neuroscience*, *14*(*10*), 1323–1329. 10.1038/nn.2903.

Machulda, M. M., Senjem, M. L., Weigand, S. D., Smith, G. E., Ivnik, R. J., Boeve, B. F. et al. (2009). Functional magnetic resonance imaging changes in amnestic and nonamnestic mild cognitive impairment during encoding and recognition tasks. *Journal of the International Neuropsychological Society*, *15*(*3*), 372–382. 10.1017/S1355617709090523.

Malcolm, G. L., Groen, I. I. A., & Baker, C. I. (2016). Making sense of real-world scenes. *Trends in Cognitive Sciences*, *20*(*11*), 843–856. 10.1016/j.tics.2016.09.003.

Memel, M., & Ryan, L. (2017). Visual integration enhances associative memory equally for young and older adults without reducing hippocampal encoding activation. *Neuropsychologia*, *100*, 195–206. 10.1016/j.neuropsychologia.2017.04.031.

Mistridis, P., Egli, S. C., Iverson, G. L., Berres, M., Willmes, K., Welsh-Bohmer, K. A. et al. (2015). Considering the base rates of low performance in cognitively healthy older adults improves the accuracy to identify neurocognitive impairment with the consortium to establish a registry for Alzheimer's disease-neuropsychological assessment battery (CERAD-NAB). *European Archives of Psychiatry and Clinical Neuroscience*, *265*(*5*), 407–417. 10.1007/s00406-014-0571-z.

Molinuevo, J. L., Rabin, L. A., Amariglio, R., Buckley, R., Dubois, B., Ellis, K. A. et al. (2017). Implementation of subjective cognitive decline criteria in research studies. *Alzheimer's & Dementia*, *13*(*3*), 296–311. 10.1016/j.jalz.2016.09.012.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*(*1*), 97–113. 10.1016/0028-3932(71)90067-4.

Park, D. C., Polk, T. A., Park, R., Minear, M., Savage, A., & Smith, M. R. (2004). Aging reduces neural specialization in ventral visual cortex. *Proceedings of the National Academy of Sciences*, *101*(*35*), 13091–13095. 10.1073/pnas.0405148101.

Park, S., Brady, T. F., Greene, M. R., & Oliva, A. (2011). Disentangling scene content from spatial boundary: Complementary roles for the parahippocampal place area and lateral occipital complex in representing real-world scenes. *Journal of Neuroscience*, *31*(*4*), 1333–1340. 10.1523/JNEUROSCI.3885-10.2011.

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.r-project.org/.

Rabin, L. A., Smart, C. M., Crane, P. K., Amariglio, R. E., Berman, L. M., Boada, M. et al. (2015). Subjective cognitive decline in older adults: An overview of self-report measures used across 19 international research studies. *Journal of Alzheimer's Disease*, *48*(*s1*), S63–S86. 10.3233/JAD-150154.

Reisberg, B., Shulman, M. B., Torossian, C., Leng, L., & Zhu, W. (2010). Outcome over seven years of healthy adults with and without subjective cognitive impairment. *Alzheimer's & Dementia*, *6*(*1*), 11–24. 10.1016/j.jalz.2009.10.002.

Reitan, R. M., & Wolfson, D. (1986). The Halstead-Reitan Neuropsychological Test Battery. In *The Neuropsychology Handbook: Behavioral and Clinical Perspectives* (pp. 134–160). Springer Publishing Co, Danny Wedding, Arthur MacNeill Horton, Jr., Jeffrey Webster. New York.

Rey, A. (1958). *L'examen clinique en psychologie. [The Clinical Examination in Psychology.]* (p. 222). Presses Universitaries De France, Paris.

Risacher, S. L., WuDunn, D., Pepin, S. M., MaGee, T. R., McDonald, B. C., Flashman, L. A. et al. (2013). Visual contrast sensitivity in Alzheimer's disease, mild cognitive impairment, and older adults with cognitive complaints. *Neurobiology of Aging*, *34*(*4*), 1133–1144. 10.1016/j.neurobiolaging.2012.08.007.

Ruiz-Rizzo, A. L., Bublak, P., Redel, P., Grimmer, T., Müller, H. J., Sorg, C. et al. (2017). Simultaneous object perception deficits are related to reduced visual processing speed in amnestic mild cognitive impairment. *Neurobiology of Aging*, *55*, 132–142. 10.1016/j.neurobiolaging.2017.03.029.

Russell, B. C., Torralba, A., Murphy, K. P., & Freeman, W. T. (2008). LabelMe: A database and web-based tool for image annotation. *International Journal of Computer Vision*, *77*(*1–3*), 157–173. 10.1007/s11263-007-0090-8.

Smith, S. M. (2002). Fast robust automated brain extraction. *Human Brain Mapping*, *17*(*3*), 143–155. 10.1002/hbm.10062.

Snodgrass, J. G., & Corwin, J. (1988). Pragmatics of measuring recognition memory: Applications to dementia and amnesia. *Journal of Experimental Psychology: General*, *117*(*1*), 34–50. 10.1037/0096-3445.117.1.34.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*(*6*), 643–662. 10.1037/h0054651.

Trelle, A. N., Henson, R. N., Green, D. A. E., & Simons, J. S. (2017). Declines in representational quality and strategic retrieval processes contribute to age-related increases in false recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *43*(*12*), 1883. 10.1037/xlm0000412.

Viviano, R. P., & Damoiseaux, J. S. (2020). Functional neuroimaging in subjective cognitive decline: Current status and a research path forward. *Alzheimer's Research & Therapy*, *12*(*1*), 23. 10.1186/s13195-020-00591-9.

Viviano, R. P., Hayes, J. M., Pruitt, P. J., Fernandez, Z. J., van Rooden, S., van der Grond, J. et al. (2019). Aberrant memory system connectivity and working memory performance in subjective cognitive decline. *NeuroImage*, *185*, 556–564. 10.1016/j.neuroimage.2018.10.015.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale* | 3rd ed. Psychological Corporation, San Antonio, TX.

Wechsler, D. (2009). *Wechsler Memory Scale* | 4th ed.

Wechsler, D. (2011). *Wechsler Abbreviated Scale of Intelligence* | 2nd ed.

Woolrich, M. W., Ripley, B. D., Brady, M., & Smith, S. M. (2001). Temporal autocorrelation in univariate linear Modeling of FMRI data. *NeuroImage*, *14*(*6*), 1370–1386. 10.1006/nimg.2001.0931.

Yarkoni, T., Poldrack, R. A., Nichols, T. E., Van Essen, D. C., & Wager, T. D. (2011). Large-scale automated synthesis of human functional neuroimaging data. *Nature Methods*, *8*(*8*), 665–670. 10.1038/nmeth.1635.

Yesavage, J. A., Brink, T. L., Rose, T. L., Lum, O., Huang, V., Adey, M. et al. (1982). Development and validation of a geriatric depression screening scale: A preliminary report. *Journal of Psychiatric Research*, *17*(*1*), 37–49. 10.1016/0022-3956(82)90033-4.

Yeung, L.-K., Ryan, J. D., Cowell, R. A., & Barense, M. D. (2013). Recognition memory impairments caused by false recognition of novel objects. *Journal of Experimental Psychology: General*, *142*(*4*), 1384–1397. 10.1037/a0034021.

Yin, Q., Johnson, E. L., Tang, L., Auguste, K. I., Knight, R. T., Asano, E. et al. (2020). Direct brain recordings reveal occipital cortex involvement in memory development. *Neuropsychologia*, *148*, 107625. 10.1016/j.neuropsychologia.2020.107625.