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Emotional enhancement of perceptual priming is preserved in aging and early-stage Alzheimer's disease

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Abstract

Perceptual priming for emotionally-negative and neutral scenes was tested in early-stage Alzheimer's disease (AD) patients and healthy younger, middle-aged and older adults. In the study phase, participants rated the scenes for their arousal properties. In the test phase, studied and novel scenes were initially presented subliminally, and the exposure duration was gradually increased until a valence categorization was made. The difference in exposure duration required to categorize novel versus studied items was the dependent measure of priming. Aversive content increased the magnitude of priming, an effect that was preserved in healthy aging and AD. Results from an immediate recognition memory test showed that the priming effects could not be attributable to enhanced explicit memory for the aversive scenes. These findings implicate a dissociation between the modulatory effect of emotion across implicit and explicit forms of memory in aging and early-stage AD.

Keywords: Amygdala; Affect; Perceptual defense; Dementia; Declarative memory; Repetition priming

1. Introduction

Alzheimer's disease (AD) is a progressive aging disorder whose early hallmarks include profound amnesia accompanied by neuropathological changes in the medial temporal lobe and associated structures (Van Hoesen, 1997). The mnemonic deficits associated with AD have been well studied. On explicit (declarative or conscious) memory tasks, AD patients perform poorly even in early-stages of the disease, and explicit memory loss is a core cognitive feature of the disease (McKhann et al., 1984). On implicit (non-declarative or non-conscious) memory tasks, their performance is less consistent. AD patients typically show intact motor skill learning (Eslinger & Damasio, 1986; Gabrieli, Corkin, Mickel, & Growdon, 1993) and habit learning (Eldridge, Knowlton, & Masterman, 2002). However, they exhibit impaired eyeblink conditioning, even on simple tasks (Solomon, Levine, Bein, & Pendlebury, 1991; Woodruff-Pak, Finkbiner, & Sass, 1990; Woodruff-Pak, Romano, & Papka, 1996). Priming studies show considerable variability in performance in healthy aging and AD, due in part to differences in experimental procedures, potential contamination by explicit processes, and relative dependence on conceptual–perceptual or identification-production processes (Fleischman & Gabrieli, 1998; LaVoie & Light, 1994; Meiran & Jelicic, 1995).

All of these studies have examined memory for material that is devoid of emotional content. Given the unique distribution of pathological changes in AD, which include the amygdala and associated limbic structures that mediate emotional information processing (Mann, 1992; Scott, DeKosky, Sparks, Knox, & Scheff, 1992; Unger, Lapham, McNeill, Eskin, & Hamill, 1991), it is important to characterize emotional functions and their influence on memory in AD. Several studies have concluded that emotional changes in perception, attention and comportment are not cardinal features of early-

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stage AD. For example, early-stage AD patients show normal orienting and sustained attentional biases to emotionally-aversive scenes presented simultaneously with neutral ones (LaBar, Mesulam, Gitelman, & Weintraub, 2000). AD patients have some difficulties on facial affect perception tasks, but in many cases, the impairments are reduced or eliminated when performance is covaried by cognitive test scores (Albert, Cohen, & Koff, 1991; Allender & Kaszniak, 1989; Cadieux & Greve, 1997; Hargrave, Maddock, & Stone, 2002; Koff, Zaitchik, Montepare, & Albert, 1999; Ogrocki, Hills, & Stauss, 2000; Roudier et al., 1998). These deficits likely reflect the cognitive demands of the tasks rather than a specific dysfunction of emotional processing (but see Hargrave et al., 2002). As the disease progresses, emotional changes in comportment are found in a subset of patients, incidence of depression increases and recognition of emotionally-salient stimuli, including identification of family members, declines (Deutsch & Rovner, 1991; Roberts, Ingram, Lamar, & Green, 1996; Rubin, 1990; Starkstein et al., 1995).

Given the profound amnesia associated with AD, it is difficult to assess the influence of emotion in the explicit domain. This is because emotional arousal effects on explicit memory take time to emerge (Kleinsmith & Kaplan, 1963; LaBar & Phelps, 1998), and patient performance is typically at floor on recall and recognition tests following a delay. Nonetheless, a few studies have investigated explicit memory for emotional material using short retention intervals. Hamann, Monarch, and Goldstein (2000) tested psychophysiological responses and explicit memory for emotionally-arousing and neutral scenes in a group of AD patients, age-matched controls and age-matched controls following a 2-week delay to equate overall levels of recall to the patients. Both AD patients and controls showed enhanced skin conductance responses and arousal ratings to positive and negative scenes relative to neutral ones at encoding. In age-matched controls, recall for the positive and negative scenes was enhanced relative to that for neutral scenes. This recall advantage was only found for positively-valent scenes in the AD patients. Controls tested after a 2-week delay also showed a recognition memory advantage for negative scenes relative to neutral ones, which was absent in the AD patients. Overall, however, the AD patients exhibited very low levels of recall (less than 10% of items were recalled), and recognition memory was at ceiling in controls who were tested immediately after encoding. Hamann et al. concluded that AD was associated with impaired emotional memory for negatively-valent material.

Kensinger, Brierley, Medford, Growdon, & Corkin (2002) tested younger adults, older adults and AD patients on several tasks of emotional memory and memory for emotional contexts. To equate overall performance across the populations, older adults and AD patients had an extra learning trial on the emotional memory tasks. Affective ratings for words, scenes and sentences were intact in all groups. Both younger and older adults showed a recall advantage for positive and negative scenes and words relative to neutral stimuli, an effect not found in the AD patients. On tests of emotional context memory, only young adults showed recall and recognition advantages for words encoded in emotional sentence contexts relative to neutral sentence contexts (either self-generated or experimentally-generated). No additional disadvantage was found in the AD population relative to their age-matched controls. Overall memory performance on the contextual memory tasks, however, declined from young adults to older adults to AD patients. The authors concluded that memory enhancement for emotional stimuli is selectively impaired in AD, whereas memory enhancement for emotional encoding contexts is a form of source memory impaired in healthy aging.

Other studies have reported intact explicit memory enhancement for emotional stimuli in AD. In a naturalistic study of the 1995 Kobe earthquake, Ikeda et al. (1998) found that memory for this event tested 2 months later was better than memory for a contemporaneous control event (getting an MRI scan) in AD patients. Moreover, the amount of retention, as measured by an aggregate score on a semistructured interview, correlated with remaining bilateral amygdala volume in a subset of the patients (Mori et al., 1999). A similar correlation was present between memory for the earthquake and bilateral hippocampal volume, but it was not significant after the effects of demographic variables and cognitive test scores were taken into consideration. However, no control group was included in the volumetric measurements, and it is difficult to attribute retention of this event to a single (emotional) process, since many cognitive factors also contribute to "flashbulb" memory (Rubin & Kozin, 1984).

Two studies examined memory for emotionally-arousing and neutral segments of an audiovisual story (Kazui et al., 2000; Moayeri, Cahill, Jin, & Potkin, 2000). In these experiments, participants were presented with a slide series and accompanying narrative that described an emotionally-aversive event in the middle segment of the story. Memory was tested 5 min after encoding using cued recall and recognition methods in which participants responded to questions while viewing the slides themselves. AD patients recognized events from the emotionally-arousing segment of the story better than those from the neutral portions of the story. Kazui et al. further showed that memory for the emotional middle segment was greater than in another version of the story using a neutral middle segment. In both studies, however, control subjects were near ceiling, which obscured the normal enhancement of memory for the emotionally-arousing segment relative to the initial neutral segment of the story (Cahill, Prins, Weber, & McGaugh, 1994). The different pattern of results across these and the aforementioned AD studies may reflect different degrees of arousal associated with the stimulus materials and/or population differences in disease characteristics or severity.

The studies reviewed above provide some evidence for emotional memory deficits in the explicit domain but also highlight difficulties in conducting and interpreting explicit emotional memory tasks in healthy aging and AD. It is un-

known whether the beneficial influence of emotion on memory extends to the implicit domain in these populations. Testing emotional memory implicitly may be particularly useful since some aspects of implicit memory are preserved in aging and AD. Hence, implicit tasks may be more sensitive to detect the modulatory influence of emotion on memory in aged populations. In addition, comparing emotion effects across these memory domains can further inform systems-level theories of memory and their relative susceptibility to the aging process.

Few studies have examined implicit emotional memory as a function of healthy aging. The primary paradigm developed to date involves fear conditioning. LaBar, Torpey, Cook, and Welsh-Bohmer (2004) investigated differential fear conditioning in young, middle-aged and older adults. The researchers found deficits in fear acquisition that emerged as early as middle-age, but when baseline differences in arousal and awareness of the reinforcement contingencies were controlled across groups, aging decrements in conditioned fear were eliminated. This study revealed that explicit knowledge can influence performance on differential fear conditioning tasks, especially in older participants. When such explicit influences are controlled, fear conditioning appears to be preserved in aging.

Because of the variety of implicit memory processes and their associated neural substrates, it is important to characterize aging- and AD-related changes across multiple implicit emotional memory tasks and to address whether any changes are related to explicit factors. As a first step toward this goal, we developed a novel item repetition priming task for complex scenes using a perceptual identification paradigm to investigate whether emotional enhancement of priming magnitude was impacted by healthy aging or early-stage AD. During the study phase, participants rated aversive and neutral scenes for arousal. During the test phase, studied and matched novel scenes were presented at subliminal stimulus durations, which gradually increased until a valence categorization was made. Because of this feature of the test phase, it was possible to investigate whether perceptually degraded aversive stimuli exhibited perceptual defense or perceptual vigilance (Bruner, 1992; Erdelyi, 1974), both of which may contribute to emotional modulation of perceptual forms of priming. Specifically, negative valence may influence perceptual identification though either facilitation (vigilance) or suppression (defense) of aversive featural information during the initial encoding of an emotional stimulus. As a stimulus becomes more familiar through item repetition, these emotional influences may be mitigated, which in turn would yield differential priming effects for aversive and neutral stimuli. Perceptual defense effects have not been systematically studied in aging populations, and it is unknown if they are modified by repetition priming. To rule out the potential contribution of explicit memory on priming magnitude, recognition memory for the study phase stimuli was assessed immediately following the test phase of the priming task.

2. Method

2.1. Participants

Healthy adults participating in this study spanned three age groups: younger adults (YC) aged 18–20 years (mean age = 19 years, $N = 25$, 20 female), middle-aged adults (MC) aged 50–64 years (mean age = 58 years, $N = 22$, 14 female) and older adults (OC) aged 66–80 years (mean age = 72 years, $N = 25$, 12 female). The YC group was comprised of Duke University undergraduates who were given course credit for their participation. The MC and OC groups were recruited by one of three methods: referral from the Joseph & Kathleen Bryan Alzheimer's Disease Research Center (ADRC) at Duke University Medical Center, referral from the Center for Aging and Human Development at Duke University Medical Center, or advertisements placed in on- and off-campus publications. For their participation, the MC group was compensated $10/h and the OC group was compensated $20/h. These groups were matched for level of education (mean = 16 years for both groups; MC range = 12–20 years, OC range = 13–20 years). All participants were screened by phone and by written self-report questionnaire for history of neurologic and psychiatric illness, substance abuse and current medication use.

Probable AD patients aged 71–83 years were also tested (mean age = 77, $N = 10$, 6 female). Age and level of education (mean = 14 years, range = 11–18 years) were matched to a subset of participants in the OC group, who served as their controls (mean age = 75 years, $N = 15$, 8 female). All patients were recruited from the Clinical Core patient registry of the Bryan ADRC at Duke University Medical Center. AD patients were compensated $20/h for their participation. All participants provided informed consent prior to participation in the experiment. For the AD patients, informed consent was also obtained from the spouse or primary caregiver. Recognition memory scores from one AD patient were lost due to technical error. The experimental protocol and human subjects procedures were approved for ethical considerations by the Institutional Review Board at Duke University Medical Center.

2.2. Clinical diagnosis and neuropsychological assessment procedures

Diagnosis of probable AD followed criteria established by the National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer's Disease and Related Disorders Association (McKhann et al., 1984). Patients in the Clinical Core registry underwent neurologic and neuropsychological evaluations by the Neurological Disorders Clinic gerophysicians at the Bryan ADRC. Participants in the MC, OC and AD groups underwent additional neuropsychological examinations within several months (mean = 3 months) of participation in the experiment to confirm the diagnosis of AD in the patient group and to establish the ab-

Table 1
A sample of neuropsychological test scores (means ± S.E.M.) in the Alzheimer's disease patients (AD), middle-aged control group (MC) and older control group (OC)

Test	MC	OC	AD
Mini-Mental State Exam	29.0 ± 0.2	28.6 ± 0.3	21.6 ± 1.1
Beck Depression Inventory	3.5 ± 0.7	n/a	n/a
Geriatric Depression Scale	n/a	3.5 ± 0.7	5.3 ± 1.5
Wechsler Memory I Recall—raw score	30.0 ± 1.0	31.1 ± 1.3	7.6 ± 1.5
Wechsler Memory II Recall—raw score	26.9 ± 1.1	29.0 ± 1.5	2.2 ± 1.1
Digit Span Forward Recall	9.6 ± 0.5	9.1 ± 0.5	6.9 ± 0.4
CERAD Word List—delayed recall	8.1 ± 0.3	7.8 ± 0.3	1.1 ± 0.4

n/a: not tested.

sence of cognitive deficits in the MC and OC groups. The neuropsychological battery was compiled by the Bryan ADRC and included standardized tests of memory, attention, naming and executive function. A subset of scores from this battery is summarized in Table 1. Because the experimental tasks emphasized stimuli of negative valence, the Geriatric Depression Scale (GDS) (Yesavage et al., 1983) was also administered to the OC and AD groups. There was no evidence for depression in either the AD or OC group (Table 1). In addition, a subset of the MC group ($N = 14$) completed the Beck Depression Inventory, and there was no evidence for depression in this group either (Table 1). Patients were classified as having 'mild' dementia according to their scores on the Mini-Mental State Exam (MMSE) (Folstein, Folstein, & McHugh, 1975). Following the neuropsychological evaluation session, a clinical consensus conference was held to confirm the diagnosis of the MC, OC and AD participants at the time of experimental testing. Two scorers blind to the original diagnoses (S.R.J. and L.H.W.) independently confirmed the patient classifications on a case-by-case basis in consult with the clinical neuropsychologists and behavioral neurologists at the Bryan ADRC.

2.3. Stimulus materials

Stimuli consisted of emotionally-negative and neutral complex visual scenes. The stimuli were taken from the International Affective Picture System (IAPS) (Lang, Bradley, & Cuthbert, 2001) supplemented by additional ones developed in-house to equate the categories for qualitative visual complexity, color content and presence of human figures (Yamasaki, LaBar, & McCarthy, 2002). The negative category included scenes of violence, threat, injury and disease. Examples of the images used can be found in Fichtenholtz et al. (2004), and a complete list is available from the corresponding author upon request. Arousal ratings for the pictures (1 = low, 9 = high) taken from the IAPS norms and a pilot group of undergraduate participants ranged from 5.39 to 7.50 for negative scenes (mean = 6.56) and 2.57–4.93 for neutral scenes (mean = 3.40). Valence ratings for the pictures (1 = negative, 9 = positive) ranged from 1.45 to 3.72 for negative scenes (mean = 2.11) and 3.97–6.23 for neutral scenes (mean = 4.94). We focused on negatively-valent scenes in the present study because these scenes show the most consistent explicit memory deficits in AD (Hamann et al., 2000; Kensinger et al., 2002). In addition, early-stage AD patients have intact voluntary orienting and sustained attention to these aversive scenes (LaBar et al., 2000), so any potential deficits observed could be interpreted as reflecting mnemonic rather than attentional factors.

2.4. Experimental procedure

2.4.1. Study phase

The experiment consisted of two parts—a study phase and a test phase. In the study phase, participants rated 15 aversive and 15 neutral scenes for their arousal properties on a 3-point Likert-type scale using the numeric keypad on a computer keyboard (1 = low arousal, 2 = medium arousal, 3 = high arousal). The instructions were written on the computer screen as well as verbally communicated to the participant. Each rating was made during the time the scene remained on the computer screen (stimulus duration = 3.5 s, visual angle = $24.4^\circ \times 16.8^\circ$ degrees). The rating scale appeared below each scene for the duration of the trial. Stimuli were presented in a pseudorandom order subject to the constraint that no more than two scenes of each valence were presented in a row to avoid mood induction effects. A central fixation cross remained on the screen in the inter-trial interval until the experimenter manually advanced the program to display the next scene. Superlab software (Cedrus Corporation, San Pedro, CA) was used for stimulus presentation and data collection.

Prior to the study phase, participants were given practice trials to ensure that they were comfortable with the instructions and were able to perform the ratings in the allotted time interval. Two neutral pictures taken from the IAPS set were used exclusively during the practice. The data collection portion of the study phase did not commence until each participant had successfully completed the practice trials, which were repeated as necessary.

2.4.2. Test phase: perceptual identification

During the test phase of the experiment, participants categorized the valence of 30 studied and 30 novel scenes (half negative/half neutral) using a two-alternate forced choice re-

sponse (1 = negative, 2 = neutral). Novel scenes were taken from the larger pool of IAPS and in-house pictures and were matched to the studied scenes for arousal, valence, visual complexity, color content and presence of human figures (Yamasaki et al., 2002). Valence judgments were made by double-clicking one of two computer mouse buttons. A diagram of the mouse labeling the valence category corresponding to each button was taped to the right side of the computer monitor for the subjects' reference.

Participants were informed that the scenes would flash onto the screen, and that the duration would increase with each flash. The stimuli were initially presented at a subliminal duration close to the refresh rate of the computer screen (60 Hz). The exposure duration was increased stepwise by 17 ms exposure increments until the participant made a valence judgment or until a maximum duration of 250 ms was reached (ascending perceptual identification threshold method). Less than 1% of all trials were excluded from analyses because the maximum exposure duration had been reached prior to a response by the participant. The scenes were backward masked for 100 ms following each exposure using one of eight visual masks. The masks were sized relative to the largest scene in the series and consisted of 96 rectangular elements that were randomly clipped from various scenes used in the experiment. Different elements were used for each mask, and the masks were randomly assigned to each scene presented during the test phase. After the mask, a blank screen was shown for 150 ms. Sequential scenes were separated by a 1000 ms duration fixation cross presented in the center of a blank screen. Both speed and accuracy were emphasized with equal importance to the subjects. Novel and studied scenes were intermixed in a pseudorandom order subject to the constraint that no more than two scenes of the same valence (across novel/studied) were presented consecutively. E-Prime software (Psychology Software Tools Inc., Pittsburgh, PA) was used for stimulus presentation and data collection.

Prior to the test phase, participants were given a separate practice script to familiarize themselves with the use of the computer mouse using a different valence categorization task (many of the OC and AD participants were not facile with this device). During the practice portion, participants categorized the valence of 56 faces (half happy/half neutral) using a two-alternate forced choice response (positive/neutral). Faces were used for this practice script in order to limit the introduction of additional pictures. As described for the test phase above, participants made their judgments using the two mouse buttons and were given a diagram of the mouse labeling the valence category corresponding to each button for their reference. The presentation and timing of the practice was identical to the test phase, except that there were six masks consisting of random clippings from various faces used in the practice. Subjects performed this practice portion until they expressed being comfortable with the procedure and the experimenter had observed a high percentage of correct responses.

2.4.3. Test phase: recognition memory

Although perceptual priming by the ascending exposure method is a standard measure of implicit memory, we conducted a recognition memory test for the scenes immediately following the priming test to rule out contributions of explicit memory on priming task performance. Young controls were not tested because pilot results showed that they were at ceiling on this measure. An additional older control group aged 63–80 years was tested with a 2-week delayed retention interval (OC-D group: $N = 22$, 13 female, mean age = 71 years) to determine the impact of a retention delay on recognition memory performance. Participants were given a yes/no recognition memory test in which 30 studied and 30 novel items were presented sequentially on the center of the computer screen. The novel items were chosen from the same data bank of pictures and were equated for arousal, valence and visual content to the studied pictures as described above. None of the novel pictures used in the priming test were included in the set. No more than two pictures of the same valence were presented in a row to avoid mood induction effects. The stimuli were presented on the screen until the participant made a recognition judgment by computer keypress (1 = yes, 2 = no). A 1000 ms fixation cross was presented between successive stimuli.

2.5. Statistical methods

Data from the study and test phases were analyzed separately using analysis of variance (ANOVA). Experimental group (YC, MC, OC, AD) was the between-subjects factor and emotion (negative, neutral) and priming (studied, novel) were within-subjects factors. The latter factor was only included for data from the test phase. Separate ANOVAs were computed for each of the two primary aims of the study: YC, MC and OC groups were compared to investigate the impact of healthy aging, and the AD group was compared to an age-matched subset of the OC group to investigate the impact of AD (for similar procedures, see Kensinger et al., 2002). Median reaction times were used from individual participants for analysis of reaction time data during the study phase. An alpha level of 0.05 was set for all analyses.

The dependent measure of priming was the exposure duration required to make valence categorizations during the test phase. A main effect of priming would be indicated by shorter exposure durations to studied as compared to novel items. The magnitude of the priming effect was further probed as a function of emotional content (priming X emotion interaction). A benefit of emotion on priming would be seen as an increase in priming magnitude for negative as compared to neutral items. The impact of emotion on exposure duration required to categorize items during test was also used as a dependent measure of perceptual defense (Bruner, 1992; Erdelyi, 1974).

The priming data were analyzed in three different ways. First, the data were analyzed using absolute priming scores

where absolute exposure durations in ms were compared for studied versus novel items. This is the standard measure of priming in the perceptual identification literature. However, absolute measures do not account for general slowing of information processing with age, which may confound age-related differences in priming (Fleischman & Gabrieli, 1998). Therefore, the data were also analyzed using proportional priming scores in which the priming score (i.e., the difference between exposure durations for studied and novel items) was expressed as a percentage of the exposure duration for novel items within-subjects (Keane, Gabrieli, Growdon, & Corkin, 1994). In this way, overall exposure durations required for task performance were normalized across the age groups.

The effect of emotion on both absolute and relative priming scores was re-analyzed according to the valence categorizations provided by the participants themselves in the test phase. However, there were no significant group differences in the emotion ratings (see Section 3), and the correspondence between the normative and participant ratings was relatively high for both arousal (>77% in all groups) and valence (>72% in all groups). It should be noted, though, that our study utilized 3-point arousal ratings and 2-alternative forced choice valence categorizations rather than the 9-point IAPS scales, so the ratings may not be directly comparable. Regardless, the results from this analysis were identical to the primary analysis and are not discussed further below.

Recognition memory scores were determined by subtracting hits from false alarms (corrected recognition memory). Because the YC group was not tested on this measure, we did not conduct separate analyses to examine the impact of healthy aging versus the impact of AD. Instead, all three groups whose memory was assessed immediately following the test phase of the priming study were included in a single ANOVA (MC, OC, AD), and a separate ANOVA was conducted to examine the impact of a retention delay on recognition memory performance in healthy older adults (OC versus OC-D). Separate analyses were conducted on hits, false alarms and corrected recognition scores. Post hoc ANOVAs and *t*-tests used Bonferroni-corrected *p*-values.

3. Results

3.1. Study phase: healthy aging

Healthy participants (YC, MC and OC groups) rated the aversive scenes as more arousing than the neutral scenes, as revealed by a main effect of emotion, $F(1, 68) = 2110.66$, $p < .001$. There were no group effects or group X emotion interactions. Reaction times showed a main effect of group, $F(2, 68) = 11.45$, $p < .001$, and a group X emotion interaction, $F(2, 68) = 4.12$, $p < .02$. Follow-up Bonferroni-corrected *t*-tests showed no significant group differences in reaction times to aversive scenes, but the YC group had faster reaction times to neutral scenes than the MC or OC groups.

3.2. Study phase: AD patients versus older controls

AD patients and their age-matched controls rated the negative scenes as more arousing than the neutral scenes, as revealed by a main effect of emotion, $F(1, 22) = 98.56$, $p < .00001$. Reaction times did not differ as a function of emotion. There were no significant group effects or group X emotion interactions in arousal ratings or reaction times during the study phase. Study phase data from all groups are presented in Fig. 1.

3.3. Test phase: healthy aging

An ANOVA computed on exposure durations revealed a main effect of priming, $F(1, 69) = 132.51$, $p < .001$, a main effect of group, $F(2, 69) = 11.80$, $p < .001$, and significant two-way interactions between emotion and priming, $F(1, 69) = 31.09$, $p < .001$, and emotion and group, $F(1, 69) = 13.15$, $p < .001$. The three-way interaction among group, emotion and priming was not significant. The main effect of priming indicates that exposure durations for studied scenes were shorter than those for novel scenes. The main effect of group indicates that exposure durations increased with aging. The priming effect interacted with emotion such that the magnitude of priming was greater for negative scenes than neutral scenes. The priming effect and its modulation by emotion were consistent across all age

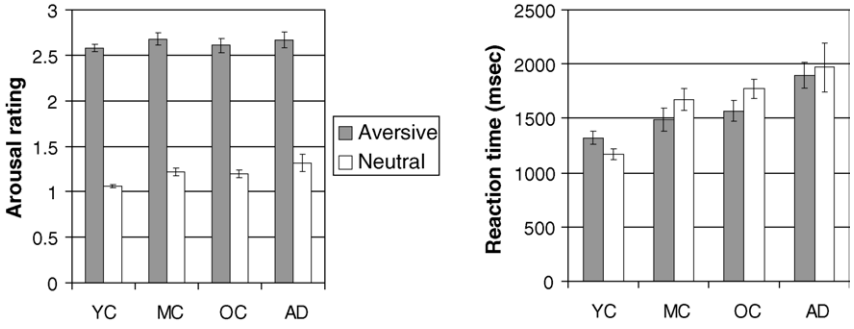

Fig. 1. Mean arousal ratings and reaction times for aversive and neutral scenes presented during the study phase. Error bars indicate S.E.M. AD: Alzheimer's disease, MC: middle-aged control, OC: older control, YC: younger control.

groups. Follow-up Bonferroni-corrected *t*-tests on the emotion X group interaction showed that negative scenes required significantly longer exposure durations than neutral scenes in YC only. This result indicates an age-dependent perceptual defense effect. However, exposure durations in general were shorter in the YC group than either the MC or OC groups.

Because exposure durations varied as a function of age, an ANOVA was also computed on proportional priming scores. The results showed a main effect of emotion, $F(1, 69) = 27.73$, $p < .001$, and a main effect of group, $F(2, 69) = 6.76$, $p < .002$. The main effect of emotion indicates that priming for negative scenes was proportionally greater than priming for neutral scenes (13% priming for negative scenes versus 7% priming for neutral scenes, on average). Post hoc one-sample *t*-tests showed that the priming magnitude for neutral scenes, despite being lower than that for emotional scenes, was nonetheless above chance for all groups (all $p < .01$). The modulatory effect of emotion on proportional priming was consistent across all age groups. Follow-up Bonferroni-corrected *t*-tests on the main effect of group revealed that, overall, proportional priming was bigger in YC than either MC or OC groups. Absolute and proportional priming data from all participants are presented in Fig. 2.

3.4. Test phase: AD patients versus older controls

An ANOVA computed on exposure durations revealed a main effect of priming, $F(1, 23) = 7.93$, $p < .01$, and an emotion X priming interaction, $F(1, 23) = 8.34$, $p < .009$. The three-way interaction among group, emotion and priming was not significant. The main effect of priming indicates shorter exposure durations for studied items relative to novel items. Furthermore, the priming effect was increased in magnitude for negative scenes relative to neutral scenes. The emotional enhancement of priming magnitude was equivalent across groups.

An ANOVA computed on proportional priming scores revealed a main effect of emotion, $F(1, 23) = 8.58$, $p < .008$. The main effect of emotion indicates better priming for negative scenes compared to neutral scenes. Emotional enhancement of priming magnitude was equivalent across the groups, although we note that, in contrast to controls, AD patients did not show significant priming for the neutral scenes (one-sample *t*-test: $t < 1$).

Due to the relatively small sample size in the AD group, we also analyzed their proportional priming data individually. The proportional priming scores for neutral scenes were subtracted from those for the negative scenes to derive an emotional difference score. A difference score of zero indicates no relative priming advantage for negative scenes compared to neutral ones. According to this measure, 7 of 10 AD patients (70%) showed a relative priming advantage for negative scenes. Only one AD patient scored more than 2 S.D. units away from the mean of the OC group on this measure, and it was in the direction of greater relative priming for negative scenes. Emotional difference scores are presented in Fig. 3.

Table 2
Recognition memory scores (means ± S.E.M.) as a function of emotional category in the Alzheimer's disease patients (AD), middle-aged control group (MC), older control group (OC) and older control group with a 2-week retention interval (OC-D)

Emotion	Group	Hits	False alarms	Corrected recognition
Aversive	MC	13.2 ± 0.5	2.1 ± 0.2	11.1 ± 0.6
	OC	13.3 ± 0.3	4.0 ± 0.6	9.3 ± 0.7
	AD	11.6 ± 0.8	7.9 ± 1.5	3.7 ± 1.4
	OC-D	11.5 ± 0.6	5.1 ± 0.6	6.5 ± 0.5
Neutral	MC	13.5 ± 0.5	0.7 ± 0.2	12.8 ± 0.4
	OC	11.9 ± 0.8	1.3 ± 0.2	10.6 ± 0.8
	AD	10.4 ± 1.4	5.9 ± 1.4	4.6 ± 1.7
	OC-D	6.8 ± 0.8	1.6 ± 0.4	5.2 ± 0.7

3.5. Test phase: recognition memory

A two-way mixed ANOVA conducted on the corrected recognition memory scores from all three groups with immediate memory testing (MC, OC, AD) revealed a significant main effect of emotion, $F(1, 44) = 32.60$, $p < .012$, and a significant main effect of group, $F(2, 44) = 18.06$, $p < .000002$ (see Table 2). The main effect of emotion reflected higher corrected recognition memory scores for neutral than aversive pictures. Post hoc ANOVAs on the main effect of group revealed worse memory overall in the AD group than in the MC and OC groups ($p < .0007$), who did not differ from each other ($p = .138$). The corrected recognition scores were broken down into analyses for hits and false alarms separately. A two-way mixed ANOVA conducted on hits revealed only a significant main effect of group, $F(2, 44) = 3.59$, $p < .036$. Post hoc ANOVAs revealed lower hit rates in the AD group compared to the MC group ($p < .024$). The OC group had intermediate hit rates that were not significantly different from either group ($p > .21$). A two-way mixed ANOVA conducted on false alarms revealed significant main effects of emotion, $F(1, 44) = 14.89$, $p < .0004$, and group, $F(2, 44) = 24.80$, $p < .00000006$. The main effect of emotion reflected higher false alarm rates for aversive relative to neutral pictures. Post hoc ANOVAs on the main effect of group revealed higher false alarm rates in the AD group than the OC group ($p < .0006$), who in turn had higher false alarm rates than the MC group ($p < .033$).

These findings indicate that the emotional enhancement of priming magnitude at the immediate test was not confounded by emotional enhancement of explicit memory processes in healthy aging or AD. Hit rates showed no effect of emotion, but the aversive scenes had a higher false alarm rate than the neutral scenes. Consequently, the corrected recognition scores were characterized by a memory advantage for neutral compared to aversive scenes, the opposite pattern to that found on the priming measures. In addition, we computed correlations between the priming scores (using both abso-

lute and proportional priming indices) and the recognition memory scores (using both hits and corrected recognition indices). None of these correlations were significant for either emotional category (*r*-values ranged from −.27 to .09; all but one were negative). Inspection of individual data showed that 64% of the participants exhibited a priming advantage for aversive scenes whereas only 19% exhibited a corrected recognition advantage for the same scenes.

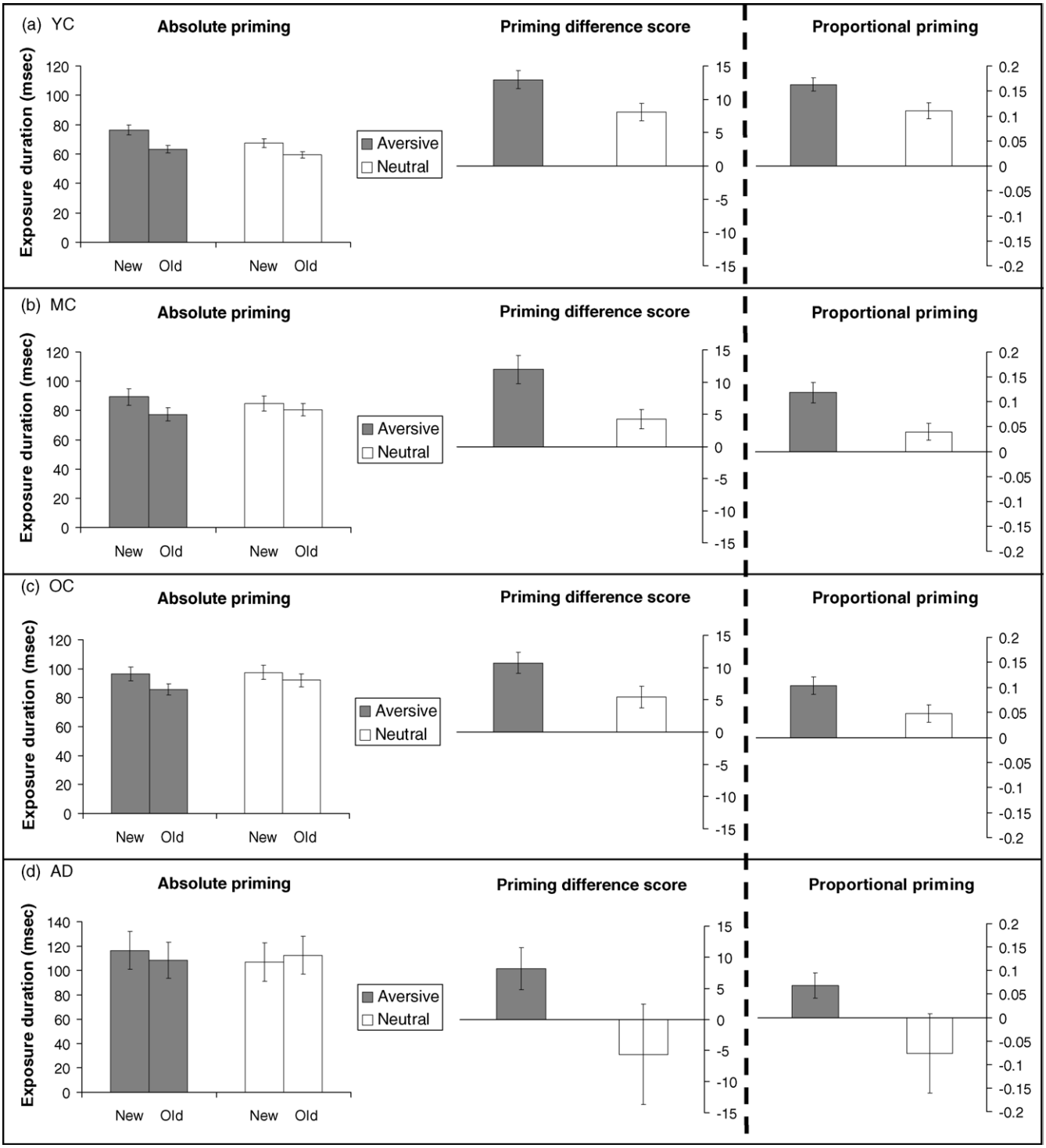

Fig. 2. Perceptual identification priming for aversive and neutral scenes. Priming is quantified using both absolute (left of dashed line) and relative (right of dashed line) scores. Middle panel presents raw difference scores (new–old) in ms for each emotional category. Right panel presents priming scores expressed as a proportion of baseline (normalized to a value of 1). Error bars indicate S.E.M. (a) YC, younger control; (b) MC, middle-aged control; (c) OC, older control and (d) AD, Alzheimer's disease.

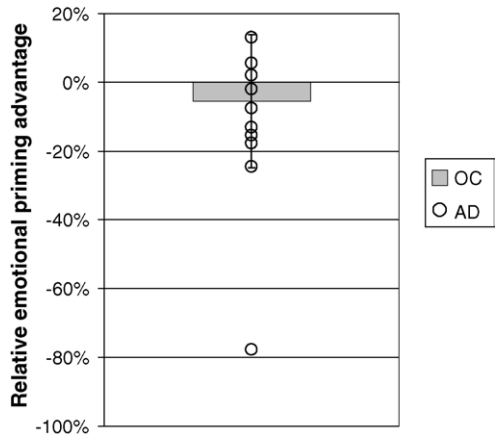

Fig. 3. Emotional difference in relative priming for the older control group (bar) and individual Alzheimer's disease (AD) patients (circles). Proportional priming scores are expressed as a difference (aversive–neutral). Scores below zero indicate a relative priming advantage for aversive scenes. Error bar indicates 2 S.D. units.

Given that the impact of emotion on explicit memory changes following a delay, we also examined recognition memory performance in a healthy older group following a 2-week retention interval (group OC-D). Their data were compared to those of the OC group, whose memory was assessed immediately following the priming test. A two-way mixed ANOVA computed on the corrected recognition scores revealed a significant main effect of group, $F(1, 44) = 22.92$, $p < .00002$, and a significant group X emotion interaction, $F(1, 44) = 7.29$, $p < .01$. The main effect of group indicates better memory overall during immediate testing. Follow-up Bonferroni-corrected *t*-tests on the interaction showed greater forgetting over time for the neutral scenes ($p < .00002$) compared to the aversive scenes ($p < .004$). As a result, the immediate testing group had a retention advantage for neutral scenes, $t(23) = -2.47$, $p < .042$, whereas neutral and aversive scenes were remembered equivalently in the delayed testing group ($p = .26$). The corrected recognition scores were broken down into analyses of hits and false alarms separately. A two-way ANOVA conducted on hit rates showed main effects of emotion, $F(1, 44) = 33.70$, $p < .0000007$, group, $F(1, 44) = 22.44$, $p < .00002$, and an emotion X group interaction, $F(1, 44) = 9.54$, $p < .003$. The main effect of emotion was due to higher hit rates for aversive compared to neutral stimuli. The main effect of group was due to higher hit rates in the immediate testing group compared to the delayed testing group. Both of these effects were qualified by an interaction that indicated higher hit rates for aversive compared to neutral stimuli only in the delayed testing group ($p < .00002$). A two-way ANOVA conducted on false alarms showed a main effect of emotion, $F(1, 44) = 47.65$, $p < .00000002$, which was due to higher false alarms to aversive compared to neutral stimuli.

These findings demonstrate an emotion X retention interval memory interaction in older adults. Older adults tested immediately following the priming test showed no significant impact of emotion on hit rates, but false alarms were higher for the aversive scenes. As a consequence, corrected recognition scores were higher for neutral scenes than for aversive ones. In contrast, older adults tested after a 2-week delay interval exhibited higher hit rates for aversive compared to neutral stimuli. This emotion benefit was offset by greater false alarms for aversive stimuli such that corrected recognition scores were not significantly different as a function of emotion category. The primary driving force behind this interaction was a steeper forgetting rate for neutral scenes in the delayed group.

4. Discussion

The present study investigated emotional modulation of repetition priming for complex visual scenes in aging and AD. A perceptual identification task was used with an ascending exposure procedure. Priming was measured using both absolute and proportional scoring methods. Irrespective of scoring method, aversive emotional content enhanced the magnitude of priming relative to neutral content. Emotional enhancement of priming magnitude was preserved in healthy aging and early-stage AD. We further showed that the emotional priming effect could not be attributable to enhanced explicit memory for the emotional scenes at the time of the priming test. Collectively, these results reveal a novel emotional priming effect and show a dissociation between the modulatory influence of emotion across implicit and explicit forms of memory in aging and AD.

4.1. Integration with existing literature

Data from the study phase indicate that older adults and AD patients are sensitive to the arousing properties of visual scenes during their initial encoding. These results support previous studies using both self-report and psychophysiological indices of arousal during encoding (Hamann et al., 2000; Kensinger et al., 2002; LaBar et al., 2000). In addition, data from the test phase provide an opportunity to examine the 'perceptual defense' effect in emotional perception (Bruner, 1992; Erdelyi, 1974). In this phase, stimuli were initially presented subliminally and exposure duration was gradually increased until a categorical judgment was made. Perceptual defense was quantified as longer exposure durations required to categorize emotional relative to neutral items under such degraded perceptual conditions. Importantly, visual properties of the stimuli were equated across the emotion categories so that perceptual defense could not be attributable to differences in lower level visual features across the stimulus categories. The perceptual defense effect was found in young adults but was reduced in aging. However, exposure durations were shorter overall in the younger control group, so the effect of aging on perceptual defense must be interpreted with caution.

Despite intact arousal ratings and emotional priming effects, healthy aging impacted priming magnitude overall. We

found a detrimental effect of healthy aging on overall priming but only when proportional scoring was used. Previous studies of perceptual priming have reported mixed results with respect to healthy aging and AD. To our knowledge, the present study is the first to examine perceptual identification priming using complex visual scenes. Because of this, it is difficult to evaluate the present study with respect to the existing literature, which has emphasized priming for words/pseudowords, possible/impossible objects, or nameable pictures/line drawings of objects. The paradigms closest in design to the present one are perceptual priming studies for novel, non-verbal stimuli that are perceptually degraded at test (Bondi & Kazniak, 1991; Corkin, 1982; Gabrieli et al., 1994; Grafman et al., 1990; Heindel, Salmon & Butters, 1990; Irle, Kaiser, & Naumann-Stoll, 1990; Russo & Parkin, 1993; Verfaellie, Gabrieli, Vaidya, & Croce, 1996). The majority of these studies have reported AD-associated impairments but no effects of healthy aging (but see Russo & Parkin, 1993). However, in their meta-analysis, LaVoie and Light (1994) concluded that healthy aging does impact performance on non-verbal priming tasks.

4.2. Consideration of contamination by explicit processes

In a review of the priming literature, Fleischman and Gabrieli (1998) emphasize the importance of considering potential influences of explicit processes. Amnesic patients exhibit impairments on perceptual priming tasks when stimuli are degraded at both study and test but not when stimuli are degraded only at test (Verfaellie et al., 1996). Consequently, Fleischman and Gabrieli argue that priming studies reporting aging or AD effects using degraded stimuli at both study and test may not be pure tests of implicit memory. Importantly, the present study and that of Heindel et al. (1990) used designs in which pictorial stimuli were degraded only at test. Heindel et al. (1990) found an overall priming impairment in AD, but the present study did not. It must be kept in mind, however, that Heindel et al. only examined neutral objects. Inspection of the data from the present study also shows no priming in AD patients when the neutral scenes are considered alone (Fig. 2), although the group effect was not significant in the statistical analysis. Other procedural differences across these two studies must also be considered, including the testing paradigm (picture fragment naming versus perceptual identification test), role of generation processes and stage of AD in the patient samples.

Potential influences of explicit processes were also minimized through several other design features of the present study. The specific task instruction (arousal rating versus valence categorization), the response mapping (from three to two alternatives) and the mode of responding (keypress versus mouse) were changed between study and test to reduce the impact of explicit memory for the response made in the study phase. Results from the recognition memory task directly confirm that the emotional enhancement of priming magnitude was not due to enhanced explicit memory for the emotional scenes at the time of immediate testing. None of the groups whose recognition memory was tested immediately showed a retention advantage for emotional scenes. In fact, corrected recognition scores were higher for the neutral scenes, which was due to equivalent hit rates as a function of emotional category combined with high false alarm rates for the emotional scenes, especially in older adults. In contrast, older adults tested with a 2-week retention interval exhibited both higher hit rates and false alarms for the aversive scenes, which eliminated the corrected recognition score advantage for neutral scenes. There was no correlation between the priming and explicit memory measures across participants. These results indicate that enhanced perceptual identification for emotional stimuli does not necessarily translate into enhanced explicit emotional memory. However, it is possible that on some explicit tests (e.g., Kazui et al., 2000; Moayeri et al., 2000), healthy aging participants and AD patients may benefit from implicit emotional processes, given that implicit processes can influence performance on explicit memory tests and vice versa (Roediger, 1990). The results from the delayed retention group also indicate that older adults are sensitive to emotional memory consolidation over time. This effect implies that comparisons between immediate testing in AD and delayed testing in healthy controls should be interpreted with caution, even though this procedure equates overall memory performance between groups, as shown here and in Hamann et al. (2000).

Collectively, the explicit memory findings suggest three noteworthy effects: (1) an interaction between emotional content and retention interval in older adults that implicates arousal-mediated consolidation processes, as previously shown in younger adults (Kleinsmith & Kaplan, 1963; LaBar & Phelps, 1998), (2) a magnification of false memory for emotional items in older adults relative to middle-aged adults and (3) a direct dissociation between the impact of emotion on immediate implicit and explicit memory measures in aging and AD.

4.3. Potential mechanisms underlying the emotional priming effect

There are two competing theories of long-term repetition priming phenomena—perceptual-based and response-based (e.g., Dobbins, Schnyer, Verfaellie, & Schacter, 2004). It is important to consider which of these may be operating in the present context to interpret the modulatory influence of emotion. We favor an interpretation based on a beneficial influence of emotional content on perceptual processes for several reasons. First, the nature of the priming test (perceptual identification with ascending exposure method) emphasized perceptual processes and is typically interpreted with respect to facilitated perceptual representation of the stimuli with repeated exposure (reviewed in Fleischman & Gabrieli, 1998). Second, there were several design features of our study that reduce response-based priming: (1) as dis-

cussed above, the task instructions and response mappings were changed from study to test. Subjects in the study phase were asked to provide a 3-point arousal rating for the scenes (low, medium, high), whereas in the test phase, they were asked to provide a 2-alternative forced choice valence categorization (negative, neutral). In addition, the scale was reversed across phases such that responses to negative pictures, which typically yielded '2' or '3' responses in the study phase were mapped to response '1' in the test phase. These task features significantly decrease the contribution of response-based learning to priming (Dobbins et al., 2004). (2) The modality of the manual response was changed from a computer keypress response at study to a computer mouse response at test. This change in manipulandum eliminates the contribution of habitual motor responses and motor imagery to task performance for repeated (primed) items at test. (3) Participants only received one exposure of each primed item; although response priming can occur with only a single exposure, it tends to increase with multiple exposures. (4) Preliminary results from young adults show that the same emotional enhancement occurs when the task at test is changed from a valence categorization to a spatial categorization (indoor/outdoor) (LaBar & Phelps, 2002). In this case, there is no clear relational mapping of a response from study (arousal judgment) to test (spatial judgment). Altogether, these issues suggest that response-based learning was minimal.

It is not clear exactly how emotional content interacts with perceptual processing across repeated presentations of stimuli. One issue that is important to disentangle is the relative influence of arousal and valence. Our preliminary work in young adults shows that the emotional enhancement of priming is specific to negative valence (LaBar & Phelps, 2002). Because of this negativity bias, it is possible that the effect is driven in part by perceptual defense mechanisms that are mitigated with repeated exposure. According to this account, perceptual feature analysis is specifically impaired (or inhibited) to degraded aversive stimuli, an effect that potentially decreases with subsequent presentations as the novelty value and aversiveness of the stimuli are accordingly reduced. In this way, perceptual defense mechanisms could account for the fact that aversive items show a benefit in exposure duration with repetition. Note that emotional priming could occur even if perceptual priming is not found for neutral stimuli, as with the AD patients in the present study. This is because the mechanism accounting for emotional priming is independent of the neutral priming effect. There is some evidence to support the perceptual defense account in the present study, but it cannot fully explain the findings, since (1) perceptual defense was reduced in healthy aging but emotional priming magnitude was not and (2) the emotional priming effect was found with proportional scoring, which controls for baseline differences in exposure duration as a function of emotional category (as would be the case if perceptual defense mechanisms were operating).

Another possibility is that the effect of prior presentation on perceptual identification is actually equal for neutral and aversive scenes, but less perceptual information is needed to make the valence categorization judgment for the aversive scenes at test. This could occur if, for example, a 'neutral' judgment is conferred only in the absence of any obviously aversive featural information in the scene. However, as mentioned above, identical results are obtained when participants engage in a spatial (indoor/outdoor) judgment at test, where there would be no such response advantage for aversive scenes. Thus, orientation to emotional content at test is not necessary for the effect to occur, which implicates a more general benefit of prior study for the aversive items.

Collectively, these considerations point to a synergy between processing of negative valence and covert priming operations such that aversive content incurs a greater advantage from prior study in terms of subsequent perceptual identification. This finding is consistent with other observations that repeated aversive stimuli confer perceptual advantages such as enhanced spatial contrast sensitivity (Ling, Phelps, Holmes, & Carrasco, 2004), which is known to occur in early-stages of visual processing. Further understanding of the mechanisms underlying emotional modulation of priming may be informed by additional behavioral and neurobiological investigations. For instance, neuroimaging and neuropsychological studies provide evidence that repetition priming involves modality-specific sensory processing regions (Gabrieli, 1998; Schacter & Badgaiyan, 2000). Feedback from frontolimbic structures such as the amygdala (Amaral & Price, 1984) form a putative neuroanatomical substrate for emotional modulation of perceptual priming in visual cortex. Given the involvement of the amygdala in the early-stages of AD (Mann, 1992; Scott et al., 1992; Unger et al., 1991; Van Hoesen, 1997), the present results do not support a necessary role for the amygdala in this process. Moreover, preliminary results from a patient with bilateral amygdala damage show a pattern of performance similar to that in the AD patients (LaBar & Phelps, 2002). The emotionally-aversive scenes used in the present study are known to modulate functional activity along many components of the ventral neuraxis, extending from occipitotemporal cortices to limbic regions and inferior and medial aspects of the prefrontal cortex (Lane et al., 1997; Lang et al., 1998; Taylor, Liberzon, & Koeppe, 2000; Yamasaki et al., 2002). It is possible that in advanced stages of AD, more extensive neuropathological changes to these areas individually and in combination would impair emotional modulation of priming. Moreover, cholinergic modulation can affect these neural signatures of repetition priming and their modulation by aversive content (Bentley, Vuilleumier, Thiel, Driver, & Dolan, 2003). Longitudinal studies of AD are warranted to test these ideas.

4.4. Emotional memory in healthy aging

Laboratory-based studies of explicit emotional memory in healthy aging have largely shown preserved performance on recall and recognition tasks for emotional words, scenes and audiovisual materials (e.g., Kensinger et al., 2002; Denburg,

Buchanan, Tranel, & Adolphs, 2003). However, studies of autobiographical and flashbulb memories have revealed some age-associated changes, including a positivity bias in memory that may reflect aging differences in motivational focus (Kennedy, Mather, & Carstensen, 2004) and aging differences in coping strategies that affect memory for emotional intensity (Levine & Bluck, 1997). In addition to these effects, the explicit memory results from the present study indicate that older adults may be more susceptible to false alarming on recognition memory tests for emotional items, which may have implications in applied settings. However, our findings also showed that older adults do exhibit emotional modulation of recognition memory with delayed retention intervals, albeit without the full crossover interaction sometimes seen in behavioral studies of emotional memory (Kleinsmith & Kaplan, 1963; but see LaBar & Phelps, 1998).

Very few studies of implicit emotional memory have been conducted in healthy aging. In conjunction with our previous study of fear conditioning (LaBar et al., 2004), the present results suggest that implicit emotional memory processes are preserved in healthy aging. Given the heterogeneity of implicit memory functions and associated brain systems, it will be important to determine if emotional effects hold across different implicit memory tests. This may be a fruitful line for future investigations of emotion in aging, since baseline differences in memory performance across age groups can be better controlled.

4.5. Limitations and future directions

The present study has several limitations that should be addressed in future research. First, the sample size of AD patients was relatively small but was nonetheless clinically homogeneous. Individual subject analyses confirmed the group-averaged statistical results (Fig. 3), but future studies should replicate the findings on a larger sample of AD patients at various stages in the progression of the disease. Second, the present study involved only aversive and neutral scenes. It is unknown if aging or AD impacts the modulatory effect of emotion using positively-valent scenes or whether arousal or valence dimensions of emotion are differentially affected. Finally, it is unknown whether emotional enhancement of perceptual priming occurs for other stimulus materials, including nameable pictures, objects or words that are more commonly used in implicit memory studies of aging and AD.

The present results suggest that emotional cues can facilitate implicit memory in healthy aging and early-stage AD, at least for negatively-valent material. The beneficial effect of emotion was not evident on an immediate recognition memory test using the same stimuli, which implicates a dissociation in the modulatory effect of emotion across memory domains. Covert processing of emotional information may nonetheless improve other facets of memory and comportment in healthy aging and AD. Future studies are needed to determine the circumstances under which emotion is potentially useful as a means to partially compensate for age-associated cognitive decline.

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