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Previous studies have attributed declining episodic memory in increased adult age to less efficient contextual markers that are typically associated with ventromedial prefrontal cortex function (e.g., Allen et al., 2005). However, this previous research found the link only for negative affect. Ashby, Isen, and Turken (1999) predicted that individual differences in positive affect should also have an impact on cognitive performance. The present study therefore extended our earlier work on negative affect to positive affect and showed that individual differences in NEO Extraversion scores (a proxy for affective intensity) moderated age differences in episodic memory. Older adults with lower extraversion scores performed more poorly on a test of long-term memory (the Rey Auditory Verbal Learning Task—RA VLT) than did older adults with high extraversion scores. Yet no such effect was found on a test of short-term memory (RA VLT Trial 1). Furthermore, restricting analyses to those high in extraversion (i.e., high affective intensity) eliminate age effects on long-term memory. We propose that adult age is often characterised by a decline in affective intensity (sometimes resulting in weaker positive affective states), which might lead to encoding of fewer/weaker contextual markers at study, which then impairs later recall from long-term memory.

**Keywords:** Ageing; Episodic memory; Individual differences; Positive affect.

Studies of healthy older adults often demonstrate age-related declines in a variety of performance domains, including cognitive, emotional, and motor processing (Drag & Bieliauskas, 2010). Predictably, senescence is associated with subtle functional declines in cognition (Dennis & Cabeza, 2008), although the nature of these changes and the mechanisms underlying the trajectory of primary ageing are less well understood. One characteristic of advancing age receiving considerable interest in recent years is the consistent pattern of poorer contextual long-term memory relative to younger adults (Allen et al., 2005; Light, 1991, 1992). By “contextual”, we refer here to episodic memory—the personally-experienced, conscious recollection of life events (Tulving, 1972, 1983). Episodic memory is of particular interest in cognitive ageing research, because it appears to deteriorate with age, whereas semantic memory, reflecting the acquisition of general factual information, appears to be relatively well preserved (Allen, Sliwinski, & Bowie, 2002; Allen, Sliwinski, Bowie, & Madden, 2002; Light, 1992; Mitchell, 1989). Inasmuch as episodic memories can be emotional, and that emotion can improve memory performance, it is of particular interest to investigate the neurocognitive system(s) underlying the relationship between emotion and...
memory (see Dolcos et al., 2011 this issue), and to link observed neuropsychological changes in these dimensions with the putative neural substrates.

The goal of the present study was to examine (1) whether the deterioration in episodic memory is due to age-related decline in long-term memory retrieval (not short-term memory), and (2) whether the deterioration is associated with age-related declines in positive affective intensity. Such an association would provide additional support for the earlier observation by Allen et al. (2005), that negative affect mediated age differences in episodic memory. Our hypothesis is that individual differences in positive affective intensity (as measured by NEO Extraversion) will moderate age differences in episodic memory. Specifically, older adults with lower positive/affective intensity will show episodic long-term memory (LTM) deficits relative to older adults with higher positive affective intensity and relative to younger adults.

Although Tulving (1972) emphasised temporal context, and nonhuman animal research has emphasised the spatial context (e.g., O’Keefe & Nadel, 1978), researchers are becoming progressively more interested in “emotion as context” in memory, partly due to phenomena such as flashbulb memories (Allen, Kaut, & Lord, 2008). Accordingly, we limit our focus here to emotional contextual markers. A core assumption of the present study is that said contextual markers (singular or multiple) are stored with event memory traces, and that contextual markers (i.e., affective labels or tags) are used to retrieve the event representation from long-term episodic memory (Tulving, 1972). Note that we do not wish to determine whether age differences in episodic memory are due to encoding or retrieval deficits; indeed, we suspect that both are present. Rather, we are interested in determining whether individual differences in positive affective intensity, which likely impacts the efficiency of forming contextual markers, influences retrieval accuracy. In the present study, we operationalise positive affect (one aspect of this emotional marker system) as NEO Extraversion scores. Positive affect is taken here as an index of positive emotional activation level. We then examine how individual differences in positive affective intensity are related to age differences in episodic memory.

Gupta et al. (2009) have proposed that choices or selections in emotional decision-making tasks involve two components: (1) elicitation of an emotional representation (i.e., a bodily or somatic set of responses) integrated with a previously experienced event (episodic memory), and (2) the formation of a self-referential memory code that can be updated over time, thus taking advantage of accumulated feedback concerning the advantageous or disadvantageous nature of a given choice. Applying these emotional decision-making concepts to episodic memory, remembering a previously experienced event would first involve an association between the pattern of emotional-physical responses to an event with the sensory stimuli constituting the event itself; this compound memory code would further be indexed with one’s personal (autobiographical) perspective of the event that could be updated over time. The formation of the emotional contextual marker is thought to be associated with ventromedial prefrontal cortex (VMPFC) and/or amygdalar processes, whereas the updating over time is associated with hippocampal processes (Gupta et al., 2009). Evidence for the involvement of the VMPFC in integrating the emotional connotation of events in episodic memory can be found in Brand and Markowitsch (2008). We hypothesise that increased adult age is often (though not always) associated with reduced efficiency encoding the emotional context of events. From an evolutionary psychology perspective, this hypothesised deficit is important because of the survival value of the affective tone of experiences—failing to accurately remember that an event is potentially threatening can undermine the odds of individual adaptation to this threatening situation in the future (Allen et al., 2005, 2008). Note that the proposed deficit in forming emotional contextual markers would likely lead to poor episodic memory both for emotional events and for nonemotional events. The reason is that nonemotional memories still have emotional contextual markers, such as the emotional state of the subject during encoding. We suspect that the same neural circuitry discussed by Gupta et al. (2009) and Allen et al. (2005) are involved in encoding and retrieval.

Having previously provided evidence of a dissociation between increased adult age and long-term memory type—namely, that older adults show a decrement in episodic memory but not in semantic memory (Allen et al., 2005)—our interest in the present study is to further determine the locus of this loss of episodic memory precision. We suspect that older adults are forming less effective emotional contextual markers than are younger adults (e.g., Allen et al.,
2005). If this is truly the case, then variables that modulate age differences in episodic memory should be unrelated to observed age differences in memory components that do not require long-term memory retrieval. For example, age differences in short-term memory tend to be attenuated, if they exist at all, compared with age differences in long-term episodic memory (Kausler, 1991). Indeed, there are no appreciable age differences in short-term memory for information held in conscious awareness (termed primary memory), but there are age differences in short-term memory for information that must be retrieved back into conscious awareness (termed secondary memory; see Coyne, Allen, & Wickens, 1986). Moreover, we suspect that psychometric indices of long-term (episodic) memory and affective tone (i.e., emotion/personality) are functionally correlated—reflecting a common underlying neural system—which can be distinguished from the neural network(s) supporting short-term (working) memory and semantic memory. In the present study, we examine age differences in short-term memory (STM—specifically primary memory) and long-term episodic memory (LTM, or STM secondary memory that also requires retrieval) performance to determine whether they are differentially influenced by individual differences in emotional activation levels (measured by in the NEO Extraversion scale).

HOW DO WE MEASURE EMOTIONAL ACTIVATION LEVELS RELATED TO EPISODIC MEMORY?

There is a large literature on physiological measures of age differences in emotional intensity and expression. For example, Levenson, Carstenson, Friesen, and Ekman (1991) demonstrated that older adults showed a diminished heart-rate response and finger temperature response to emotional faces compared to younger adults, which suggests an attenuated autonomic nervous system response to emotional stimuli among older adults. However, behavioural (self-report) measures of affective intensity with good psychometric characteristics are difficult to obtain. Diener, Oishi, and Lucas (2003) have noted that personality measures of neuroticism and extraversion are good psychometric indices of negative and positive affect, respectively (also see Larsen, Diener, & Lucas, 2002; Rusting & Larsen, 1998). Consequently, we have argued that individual differences in personality characteristics such as neuroticism and extraversion can be used as proxies for individual differences in the regulation of affective intensity (Allen et al., 2005). That is, lower levels of neuroticism and extraversion are thought to result from either a drop in activation level (e.g., limbic-related reductions) or an increase in inhibition of affect (e.g., in the ventromedial prefrontal cortex and/or the dorsolateral prefrontal cortex). Further evidence for the utility of using individual differences in personality traits to measure ventromedial prefrontal performance has been presented by Bediou, Eimer, D’Amato, Hauk, and Calder (2009), who observed that individual differences in reward-drive moderated early event-related potentials (generated by ventromedial prefrontal activation) to angry faces (see also Beaver, Lawrence, Passamonti, & Calder, 2008). It is important to note that we are not referring to a state, but rather to a trait that, although changing slowly over time, is relatively stable. Thus, in the present study, we will use individual differences in NEO Extraversion (Costa & McCrae, 1991; a measure of traits) to measure individual differences in affective intensity due to emotional regulation.

AGE DIFFERENCES IN AFFECTIVE REGULATION

We now have psychophysiological evidence that early emotional effects can actually direct central (cognitive) attention to a given object (Shaw, Lien, Ruthruff, & Allen, 2011 this issue). Presently, we are interested in determining if early positive affective intensity effects can also modulate age differences in episodic memory. As mentioned earlier, emotional intensity (measured both physiologically and behaviourally) seems to decrease with advancing age (Levenson et al., 1991; McCrae et al., 2000). Using longitudinal data, McCrae et al. (2000) also observed a decrease in the NEO traits of neuroticism and extraversion over the adult life span. The reason for older adults’ drop in negative affect is a matter of interesting debate. Allen et al. (2005), Baena, Allen, Kaut, and Hall (2010), and Gruhn, Scheibe, and Baltes (2007) have all attributed this subtle decline to brain changes that decrease the efficiency of emotional regulation (although see also Mather & Knight, 2006). Alternatively, the
socioemotional selectivity theory proposed by Carstensen and colleagues (Carstensen, Isaacowitz, & Charles, 1999; Carstensen & Mickels, 2005; Mather & Carstensen, 2005) assumes that older adults’ relative shift towards positive affect is due to a more efficient behavioural regulation of physiological responses to emotional activation (i.e., they make a conscious effort to emphasise positive affect). However, other researchers do not necessarily find a positivity bias (e.g., Gruhn, Smith, & Baltes, 2005), and we suspect that a relative increase in positive affect with age is largely a function of greater declines in negative affect over time. Although Carstensen and colleagues might be correct that personality changes across the life span—with older adults developing a progressively stronger emphasis on positive affect—there is also clear evidence of neuropsychological changes in emotion perception and emotional/cognitive integration, as well (Baena et al., 2010; Denburg, Tranel, & Bechara, 2005; Lamar & Resnick, 2004; Phillips & Della Sala, 1999). Such changes suggest age-related differences in VMPFC function which might account for relative declines in the activation and regulation of emotional tone (Baena et al., 2010; Denburg et al., 2005; see Adolphs, Damasio, Tranel, & Damasio, 1996; Adolphs, Tranel, Damasio, & Damasio, 1995, for a discussion of the neural systems involved in processing emotions). Therefore, the present study considered how individual differences in positive affective intensity might relate to age differences in episodic memory.

A COGNITIVE NEUROSCIENCE MODEL OF AGE DIFFERENCES IN EPISODIC MEMORY

Allen et al. (2005) proposed a cognitive neuroscience model of age differences in episodic memory based in part upon Damasio’s (1994) somatic marker hypothesis (see also Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Tranel, & Damasio, 2000). The somatic marker perspective emphasises the importance of physiological manifestations, or bodily sensations, mediated by neurocognitive mechanisms as important markers associated with a given experience or event. Such physiological markers naturally co-occur with sensory-perceptual stimuli as part of a unified episodic representation. Indeed, emotions are often intimately linked with event memories (Leigland, Schulz, & Janowsky, 2004), reflecting an evolutionarily privileged neural network involved in the integration of relevant affective information with significant ongoing events.

Of particular importance to the present work is the notion that the neural systems supporting emotional regulation and memory—particularly episodic/contextual memories—are closely associated with limbic-related activity (see Baena et al., 2010; Deckersbach et al., 2006), whereas other memory components, such as semantic memory and working memory, are believed to rely on a less limbic-privileged network distributed throughout the neocortex (e.g., temporal and lateral prefrontal cortex) (refer to Table 1). By limbic, we refer here to portions of the medial temporal lobes, including the hippocampus, amygdala, and insula, along with connectivity to more frontal-situated limbic regions including the prefrontal cortex and anterior cingulate cortex (ACC). Given that these areas of limbic anatomy have been shown to decline in neuronal and white matter integrity with advancing age (Dennis & Cabeza, 2008), we might reasonably expect to see age-related declines on neuropsychological measures posited to emphasise these components of the limbic neural network. More specifically, healthy older adults should demonstrate relative reductions in episodic memories and certain dimensions of emotional processing (i.e., emotional intensity, emotion-memory integration).

Accordingly, we reiterate the premise of our work here, anticipating that psychometric measures of a disposition towards positive affective intensity (as measured by NEO Extraversion) will modulate performance on measures of memory recall. Inherent in this prediction is the supposition that subtle neuropsychological changes among healthy older adults affecting limbic and prefrontal cortex processing will yield psychometric evidence of those processing domains converging on a similar neurocognitive network (i.e., Episodic memory + Emotional regulation).

AN EMBELLISHED VERSION OF THIS MODEL APPLIED TO POSITIVE AFFECT

Considerable interest has centred on the apparent phylogenetically conserved neural systems involved in animal and human emotionality (i.e.,
again, principally limbic in nature; see Holland & Gallagher, 2004; Lane & Nadel, 2000; Quirk & Beer, 2006), and now growing attention has been given more recently to discussions of the neural underpinnings of human personality and how this is related to human emotionality (Deckersbach et al., 2006; Fischer, Wik, & Fredrikson, 1997; Mak, Hu, Zhang, Xiao, & Lee, 2009; Wright et al., 2006). Although the cognitive interface between emotional architecture and human personality is certainly multidimensional, previous research seems to have focused almost exclusively on negative affect (e.g., neuroticism), quite possibly due to its relevance for studies of fear, anxiety, and related psychological disorders. Nevertheless, neuroimaging studies have recently examined the neural regions and systems involved in psychometric indices of both negative and positive affect (NEO-FFI, Neuroticism and Extraversion, respectively), reinforcing the role of limbic structures such as the amygdala, insula, anterior cingulate cortex (ACC), and orbitofrontal cortical regions in negative and positive dimensions of personality (see Deckersbach et al., 2006; Mak et al., 2009; Wright et al., 2006). Importantly for our purposes here, imaging studies support our contention that levels of positive affect—as reflected in individual differences in extraversion—share a similar network with the negative affect system; however, these personality dimensions are likely to show some degree of differential reliance on certain medial temporal and prefrontal regions (see Table 1).

It is noteworthy that the literature on positive affect emphasises the role of dopamine (DA) in emotional activation and regulation (Ashby, Isen, & Turken 1999; Braver et al., 2001), a finding that is of further interest given the distribution of this neurotransmitter to many of the aforementioned limbic structures (e.g., amygdala, hippocampus, prefrontal cortex). Mak et al. (2009), speculating on the role of dopamine in the emotional regulation of cognition, note that positive affect (i.e., elevating DA levels) might influence memory performance via the dopaminergic interface with prefrontal memory circuits. Accordingly, it is reasonable to expect that individual differences along the personality dimension of positive affective intensity (i.e., extraversion), inasmuch as this reflects variations in the underlying architectural and physiological characteristics of subcortical (Fischer et al., 1997) and neocortical limbic networks (Deckersbach et al., 2006; Wright et al., 2006), might influence the emotive "tags" or contextual markers (Damasio, 1994) important for memory development. Ashby et al. (1999) suggest that increases in positive affective intensity should facilitate episodic memory, which reinforces the notion that emotional status influences memory performance (Allen et al., 2005; Baena et al., 2010). Moreover, this line of reasoning emphasises the convergence of emotional processes and memory-related activities on regions of the prefrontal cortex, thereby extending the somatic marker hypothesis (Bechara et al., 1994, 2000; Damasio, 1994) and supporting the current psychometric approach to the emotion-memory interface.

THE PRESENT STUDY

The psychometric approach used here is reflected in Table 1. Previous work has focused on the relationship between negative affect—measured by NEO Neuroticism scores—and episodic memory (see Allen et al., 2005; Baena et al., 2010). In the current work, level of positive affect was the personality dimension of interest (measured by NEO Extraversion scores), coupled with measures of immediate and delayed memory recall (RAVLT), collectively taken as behavioural indices of underlying neuropsychological regions of interest. Naturally, there are no direct measures of anatomy or neurophysiology in the approach used here; however, select neuroimaging studies from the extant neuroscience literature offer considerable support for the limbic network involved in psychometric indicators of positive affect (Deckersbach et al., 2006; Mak et al., 2009; Wright et al., 2006), while substantiating the convergence of emotion and episodic memory on limbic and prefrontal regions. We expect immediate, or short-term memory (especially STM that involves primary memory), to be somewhat less dependent on limbic-related regions (see DLPFC), although STM of the secondary memory type does show evidence of hippocampal processing (e.g., see Hannula & Ranganath, 2008; Hannula, Ryan, Tranel, & Cohen, 2006).

To assess the performance on memory recall, we used Rey Auditory Verbal Learning Test (RAVLT), which contains five trials. Participants observed the 15 words individually and were asked to recall the words immediately after the learning trial for the first four trials (the immediate recall) and recall the words 20 minutes later for the fifth trial (the delayed recall). To equate...
the relative difficulty of immediate recall (STM) and delayed recall (LTM), we used the performance of Trial 1 for the STM assessment (assuming this to be difficult because it included only a single learning trial even though it involved immediate recall) and the performance of Trial 5 for the LTM assessment—which did not include a learning component. This is an important design aspect inasmuch as we did not want increased difficulty for long-term recall to be a potential influence on any observed interactions with age group, extraversion level, or memory type. The key difference then, between Trial 1 and Delayed Recall on the RA VLT, is that the former involves very little in the way of retrieval because this information is still likely to be active in primary memory (conscious awareness; see Coyne et al., 1986), whereas the latter involves considerable retrieval load. If the efficiency of emotional regulation (as measured by NEO levels) interacts with age differences in long-term episodic memory but not short-term episodic memory, then this might suggest that the neuropsychological system contributing emotional contextual “tags” is operating less efficiently, thus impacting episodic memory as well.

### METHOD

#### Participants

This study compared the performance of younger adults ($N = 39$, 18–35 years, mean age = 23.67 years, 25 women and 14 men); and older adults ($N = 39$, 60–90 years, mean age = 69.9 years, 27 women and 12 men). Forty participants in each group were tested originally, but one individual in both age groups did not complete the study. The younger adults were sampled from students taking undergraduate courses at the University of Akron (receiving course credit for participation). All the older adults were independent-living participants from the Akron area, reported being in good health, and had no history of cerebrovascular disease. The older adults were each paid $20.00 for their participation.

To screen for dementia in older adults, we used scores the RA VLT delayed recall task (Schmidt, 1996). We compared RA VLT scores in the present sample of older adults ($N = 39$) to another sample of 17 older adults from Bush (2007). The Bush participants were diagnosed with Mild Cognitive Impairment (MCI), amnestic subtype,
using the Petersen et al. (1999) MCI criteria. A three group single-factor ANOVA (i.e., the present study younger and older adults, and MCI patients from Bush, 2007) revealed a significant difference among groups on delayed recall performance, $F(2, 92) = 43.28$, $p < .0001$, with the present sample of younger adults recalling an average of 10.85 words (maximum = 15), the healthy older adults recalling an average of 8.51 words, and the MCI sample (from Bush, 2007), recalling average of 3.65 words ($N = 17$). Tukey post hoc tests revealed that all groups differed significantly ($p < .01$). Consequently, although the present sample of older adults showed poorer episodic memory performance than the younger adults, they showed significantly better performance than the MCI sample of older adults tested by Bush, suggesting that the present sample of older adults was cognitively healthy.

Materials and procedure

The experimental session lasted less than 2 hours. All of the tests used in the present study were administered through paper-and-pencil procedures (Geriatric Depression Scale; Yesavage et al., 1983; RAVLT, and the NEO Personality Inventory—Short Form for Extraversion and Neuroticism, or NEO-PI-S, Costa & McCrae, 1991). Participants performed the tasks starting with the geriatric depression scale as part of the selection criteria (see later). The RAVLT was performed next, followed by the NEO scale. Given the past research correlating depression with poorer cognitive performance (e.g., Wilson et al., 2003), the Geriatric Depression Scale was used to screen older adults to rule out depression as a potential explanation for any observed age differences in memory performance. For the present sample of older adults, we observed no Geriatric Depression Scale scores greater than 7, and there were only two scores between 6 and 7 (scores of 10 or greater are almost always associated with depression, and scores over 5 are suggestive of depression). Thus, older adults’ performance on the present RAVLT and NEO extraversion tasks are not likely to be confounded with depression. Note that younger adults were not screened for depression inasmuch as the main concern was to ensure that older adults’ potentially poorer memory performance was not influenced by depression status.

The RAVLT administration in the present study consisted of four learning trials and five recall trials. The 15 words on the list were presented one at a time (2 s presentation rate per word). After the memory phase of each trial, participants were instructed to recall as many of the words as possible and write them down on a sheet of paper. Learning Trial 1 is considered to be a test of short-term memory (Lezak, Howesien, & Loring, 2004). Participants then repeated this process for three more learning/recall trials. After the fourth recall attempt, there was a 20-minute delay after which a fifth recall attempt was administered (no learning phase, though—that is, Trials 1–4 included both learning and recall components, but Trial 5 included just a recall component). This delayed recall trial (Trial 5) is considered to be a measure of episodic, long-term memory (Lezak et al., 2004).

Extraversion was measured using the NEO-PI-S Extraversion scale. We used a cutoff value on this scale of 43.5 to distinguish “high” and “low” participants, because it roughly divided our older and younger adult samples in half. For younger adults, the mean low Extraversion score was 39.35 and the mean high Extraversion score was 48.74. For older adults, the mean low Extraversion score was 35.95 and the mean high Extraversion score was 46.85.

RESULTS

The present study consisted of a 2 (age group: short-term memory vs. long-term episodic memory) × 2 (extraversion level: high vs. low) mixed design (age group and extraversion were measured between subjects and memory type was measured within subjects). The dependent variable was the number of words recalled (out of a possible 15). There were significant main effects for memory type, $F(1, 74) = 4.09$, $p < .05$ (STM = 9.2 words recalled; LTM = 9.7); age group, $F(1, 74) = 23.98$, $p < .001$ (younger = 10.5, older = 8.9); and extraversion level, $F(1, 74) = 5.18$, $p < .05$ (low extraversion = 8.9, high = 9.9). Also, there was an Age group × Extraversion level × Memory type interaction, $F(1, 74) = 6.20$, $p = .0125$. No other interactions reached statistical significance.

To interpret the three-way interaction, we ran simple effects analyses on extraversion level separately for both age groups crossed with both memory types. First, older adults showed a
Memory type × Extraversion level simple effect, \(F(1, 37) = 4.97, p < .05\). Also for older adults, the simple effect for extraversion was significant for LTM, \(F(1, 37) = 8.08, p < .01\) (low extraversion = 7.35 words, high = 9.74), but not for STM, \(F(1, 37) = 2.81, p = .102\) (low = 7.60, high = 8.68). For younger adults, the effect of extraversion was not significant for LTM (\(p = .603\)) (low = 11.06, high = 10.68), or STM (\(p = .186\)) (low = 9.71, high = 10.68). This interaction, then, occurred because the effect of extraversion is especially strong for older adults in the LTM condition.

We also ran simple effect analyses to determine whether age differences in LTM performance (apparent in the overall ANOVA) persisted when the analysis was restricted to those high in extraversion. This analysis showed no significant age effect (\(p = .266\)). It appears that there is little or no age-related decline in LTM for those high in extraversion (associated with above-average affective intensity).

**DISCUSSION**

The goal of the present study was to examine the hypothesis that older adults with reduced positive affective intensity (assessed using an extraversion scale) would show reduced recall from episodic LTM. We therefore reported recall data from the RAVLT as a function of age group (cognitively healthy younger and older adults), extraversion level (high vs. low), and memory type (STM vs. LTM). The key finding was that individual differences in extraversion level moderated age differences in memory type (an Age × Memory type × Extraversion level interaction). Specifically, older adults with low levels of NEO Extraversion showed poorer recall from LTM (but not STM) than older adults with high levels of NEO Extraversion. Also, older adults with higher levels of extraversion showed approximately equivalent LTM recall performance as that of younger adults.

These results are consistent with the notion that during encoding, an individual’s level of emotional intensity (i.e., NEO Extraversion)— posited here to contribute in some way to the momentary situational/emotional context—is associated with the information to be remembered (in this case, a list of 15 words). This variation of the somatic marker hypothesis (Bechara et al., 2000; Damasio, 1994) was initially proposed by Allen et al. (2005) with regard to negative affect (neuroticism). Ashby et al. (1999) hypothesised that increases in positive affect should also be related to improved cognitive performance—including episodic memory. The present results support this hypothesis by providing empirical evidence that personality-based enhancement of episodic memory performance occurs for positive affect (extraversion).

What makes the present study a sensitive test of the contextual marker hypothesis is that it included both STM (RAVLT Trial 1, little, if any, retrieval required) and LTM (RAVLT Delayed Recall) conditions and it included both individuals who scored high on the NEO-PI Extraversion scale and those who scored low. This design allowed us to seek a double dissociation between age, memory type, and extraversion level. Our critical assumptions are that (1) extraversion level is still a trait even though it appears to decrease over time in a subset of older adults, and (2) extraversion level can be used as a proxy for a disposition towards positive affective intensity (e.g., Diener et al., 2003). If we accept these assumptions, then the presently observed age differences in LTM (retention required) can be accounted for by level of positive affect (because extraversion level was not related to age effects on STM). This implies that individual differences in emotional intensity (or activation levels; operationally defined here as NEO-PI scores) in some way provide an endogenous context through which acquired information is encoded or otherwise processed for maintenance and retrieval. Accordingly, we suggest that the contextual retrieval cues among older adults with lower extraversion scores were somewhat less sufficient, thereby resulting in reduced retrieval success at RAVLT Trial 5. These results cannot be accounted for by assuming that the LTM task was more difficult than the STM task because, in fact, accuracy was slightly higher in the LTM condition. Immediate recall (from STM) is normally superior to delayed recall (from STM) but we compensated for this effect by measuring immediate recall on Trial 1 but delayed recall on Trial 5 (with the same list of 15 words used in each trial).

**Is extraversion a synonym for arousal?**

One possibility is that higher levels of extraversion simply result in higher levels of psychological
arousal, and that this higher arousal is responsible for better memory performance for extraverted older adults. We believe that this interpretation is not viable because if arousal were the key factor, then age-related improvements should have been observed for both STM and LTM in the high extraversion group—however, they were observed only for LTM. Instead, we propose that extraversion enhances the retrieval of information from episodic long-term memory because it is associated with greater affective intensity, which creates stronger contextual cues.

**Were our results due to an age artefact?**

It should be noted that, within our older adults group, individuals high in extraversion were actually older than those low in extraversion. Hence, the extraversion effect might simply reflect some type of age effect. To rule out such a confound, we performed correlation analyses on just the older adults using continuous values for age, (NEO) extraversion score, and LTM score (i.e., Trial 5). The results showed a significant correlation between extraversion level and LTM, $r = .402, p = .011$, but no correlation between age and LTM, $r = -.221, p = .176$, or age and extraversion level, $r = .039, p = .814$. This analysis suggests that our observed three-way interaction between age, extraversion level, and memory type was due to a subset of older adults with low extraversion scores performing more poorly on LTM, and that this effect was unrelated to chronological age. Indeed, for older adults, age was not significantly correlated with LTM recall.

**Could our results be due to a later-life shift in positive bias?**

As noted earlier, socioemotional selectivity theory (SST; e.g., Carstensen et al., 1999) predicts a personality change in which older adults become progressively more positively biased over time. Our older adults with higher extraversion levels may have experienced a positive bias, but we presently propose that SST has no theoretical mechanism to explain why this should result in better episodic memory performance. Our contextual marker hypothesis can explain why more salient (positive) affective contextual markers result in better memory retrieval on the part of older adults.

**Why are there age differences in STM?**

We did observe age differences in STM as well as in LTM, although older adults’ poorer STM performance was not significantly related to extraversion level. These results are in contrast to those of Coyne et al. (1986), who found no age differences in primary memory (recognition memory with no distraction after study—assumed to remain in conscious awareness) but did observe age differences for secondary memory (recognition memory with a distractor task—assumed to be outside conscious awareness and to require retrieval). One potential explanation for the difference in results between studies is that some words to be recalled in Trial 1 of the RAVLT were likely not available in conscious awareness (and may have required retrieval from LTM; i.e., a secondary memory task), so these items probably did require a certain level of retrieval.

**Neuroscience model revisited**

Consequently, we assert that a naturally occurring age-related attenuation in emotional regulation and episodic memory is supported by evidence that reductions in negative affect (neuroticism, Allen et al., 2005) or positive affect (present study) are related to poorer performance on measures of episodic memory among older adults. Indeed, this earlier study found psychometric evidence suggesting that episodic memory and emotion were closely related, whereas both of these processing dimensions were functionally unrelated to semantic memory performance (i.e., which is largely preserved in older adults; see also Drag & Bieliauskas, 2010). The present results generalise age differences in the emotional modulation of episodic memory (but not to STM) by positive affect. As illustrated in Table 1, such integration of cognitive and personality data, in the context of the deepening reductionism provided by modern neuroscience, offers a contemporary framework for testing hypotheses regarding the ageing brain (e.g., Greenwood, 2000; West, 1996). This neurocognitive perspective underscores the role of medial temporal and prefrontal limbic structures in memory and emotion (Deckersbach et al., 2006; Mak et al., 2009) while implicating alterations in limbic organisation (Dennis & Cabeza, 2008; Drag & Bieliauskas,
alone indices (e.g., NEO Extraversion) (see Swick, Senkfor, & Van Petten, 2006). Most importantly, the use of psychometric indices (e.g., NEO Extraversion) alone—organised according to a neuroscientifically shaped theoretical framework—can enhance our understanding of the ageing brain, even helping to identify functional distinctions within circumscribed regions of the cortex (Table 1). Among the many brain areas known to be affected by advancing age (see Langley & Madden, 2000; Woodruff-Pak, 1997), the frontal lobes have featured prominently in discussions of ageing (Dennis & Cabeza, 2003; Greenwood, 2000; Phillips & Della Sala, 1999; West, 1996). As part of the extensive limbic network, the prefrontal cortex (PFC) in particular is of considerable interest in studies of emotion and memory changes with age (Lamar & Resnick, 2004; Leigland et al., 2004). Most recently, psychometric studies have reinforced the notion of functional subdivisions within the prefrontal cortex (Lamar & Resnick, 2004), emphasising the relatively greater degree of age-related decline on tasks attributed to the ventromedial prefrontal cortex (VMPFC) relative to the dorsolateral prefrontal cortex (DLPFC) (see also Baena et al., 2010). As reflected in Table 1, the region of the prefrontal cortex, which broadly includes systems linking with the ventromedial and ventrolateral cortices, is construed here as constituting a functional neocortical module involved in emotional regulation, emotionally mediated decision making, and cognition. Moreover, given the neuropsychological synergy between emotion and episodic memory, it was expected that emotionality would influence episodic-like recollections to a greater degree than less limbic-related processes such as working memory (i.e., putatively more DLPFC dependent). Our finding here that age differences in positive affect moderated performance on episodic long-term, but not short-term memory, affirms this expectation, and reinforces the utility of a psychometric approach to clarifying the nature of neuropsychological change with age. The prefrontal cortex will continue to be an important region of research in the field of ageing. This vastly complex region is an essential component in the human emotional regulation and recognition system, and it is becoming increasingly clear how alterations in the prefrontal cortex relate to information processing changes with age (Dennis & Cabeza, 2008; Langley & Madden, 2000; West, 1996). In particular, the posited role for ventral and medial prefrontal regions (i.e., including ventromedial, orbitofrontal, anterior cingulate) in processing the affective “tone” of experiences (e.g., Damasio, 1994; Bechara et al., 1994/Bechara et al., 2000) provides an important theoretical perspective for investigating the ageing brain. In the context of previous work (see Lamar & Resnick, 2003; Phillips & Della Sala, 1999), we contend that portions of the prefrontal cortex change differentially with age, and when older adults show declines in select dimensions of personality (e.g., Extraversion), this likely reflects alterations in the limbic network (see Lamar & Resnick, 2004; Leigland et al., 2004). As such, psychometric investigations of prefrontal processing will be of increasing importance to help clarify neuroarchitectural and functional changes among healthy older adults.

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