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Age Differences in Reward Anticipation and Memory

Kristen L. Cushman
Western Kentucky University, kristen.cushman686@topper.wku.edu

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AGE DIFFERENCES IN REWARD ANTICIPATION AND MEMORY

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By
Kristen L. Cushman

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AGE DIFFERENCES IN REWARD ANTICIPATION AND MEMORY

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Sharon Mutter

Dr. Sharon Mutter, Director of Thesis

Dr. Steven Haggbloom

Andrew Mienaltowski

Dr. Andrew Mienaltowski

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Department of Psychology Western Kentucky University

Aging research on item- and associative-recognition memory has demonstrated that older adults are deficient in forming associations between two unrelated stimuli. Although older adult performance on tests of item-recognition is similar to younger adult performance, older adults perform worse than younger adults on tests of associative memory (Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003). In addition to the idea that younger adult performance on associative-recognition tests is superior to that of older adults, research has shown that reward cues can enhance motivated learning and item memory performance of younger adults. In an fMRI study that examined the influence of reward anticipation on episodic memory formation, Adcock and colleagues (2006) examined memory performance in response to reward cues that preceded single stimuli and found that young adult participants remembered more stimuli associated with high value reward cues than those associated with low value reward cues. The aim of the current study was to examine whether reward cues that precede a stimulus pair might enhance an association between two stimuli and influence younger and older adult performance on tests of item- and associative-recognition. Our study confirms the idea that while older adult memory for individual items is intact, older adult memory for associations is impaired (Naveh-Benjamin et al., 2003). The results supported the idea that younger and older adult item-recognition is better for high versus low reward cues, but the reward cues had no influence on the associative-recognition of either age group.

Therefore, the age-related associative deficit was not improved by reward cues that preceded each stimulus pair.

CHAPTER 1

Literature Review

Reward-based learning is an important adaptive ability, and it is critical for knowing when and where to expect rewards. In order to anticipate a reward successfully and behave accordingly, one must form an association between the reward and its accompanying predictive stimuli (Zellner & Ranaldi, 2010). Such associations are representations stored in memory, and research has shown that rewards can have modulatory effects on the memory formation of younger adults (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabreli, 2006). Many studies have shown that the aging process can negatively affect memory and reward-based learning (Bäckman, Nyberg, Lindenberger, Li, & Farde, 2006), but other studies suggest that some aspects of these processes remain relatively intact in old age (Eppinger, Herbert, & Kray, 2010; Mather & Carstensen, 2005; Mutter, DeCaro, & Plumlee, 2009). The proposed research focuses on memory, reward-based learning, reward anticipation, and the ways in which older and younger adult performance differs on tasks that involve these processes.

Episodic Memory and Recollection

The ability to encode and consciously retrieve information from a specific event is dependent upon one's episodic memory (Rönnlund, Nyberg, Bäckman, & Nilsson, 2005). According to the dual-process theory of memory, there are two dissociable mechanisms that underlie episodic memory: familiarity-based recognition and recollection (Curran, 2000). Familiarity-based recognition is assumed to be automatic and does not involve the retrieval of the spatial or temporal context that is associated with an item or event. Compared to familiarity, recollection is a slower, more controlled process that involves the conscious retrieval of an item and its context. Recollection is the process that occurs when one retrieves a representation of an event itself, as well as the conditions and circumstances under which the memory was acquired. Therefore, a memory representation associated with this mechanism of episodic memory involves the binding of a central aspect of memory to its contextual elements (Speer & Curran, 2007; Spencer & Raz, 1995). Binding occurs when two individual units, such as two words, are combined and associated together to form one cohesive unit (Naveh-Benjamin et al., 2003). Binding processes in episodic memory can therefore be assessed with associative tasks that involve the recollection of relationships between two or more stimuli (Spieler & Balota, 1996).

There are two neural components that are assumed to mediate the formation of episodic memories, the medial temporal lobe/hippocampal (MTL/HPC) component and the frontal lobe component. The MTL/HPC component is important for binding individual items into a cohesive unit. Research with rats has shown that hippocampal lesions are related to deficits in associative memory, and human studies have shown that there is increased activation in MTL/HPC areas when associative information is learned and retrieved (Wittmann et al., 2005). The MTL/HPC component is also assumed to perform automatic operations involved in memory, such as novelty encoding and cued-recall retrieval. The other component of episodic memory, the frontal lobe, is assumed to be involved in strategic, organized control processes (Naveh-Benjamin et al., 2003). In a functional magnetic resonance imaging (fMRI) study that assessed the differential contributions of these regions, Anderson et al. (2000) showed that decreased brain activity in the prefrontal cortex, but not the MTL/HPC area, was associated with stimulus encoding under a divided attention condition. This finding suggests that frontal area activation decreases when attentional resources are also decreased which supports the idea that frontal areas are important for cognitive control processes. Additional fMRI studies have shown that successful formations of episodic memories are correlated with activations in the hippocampus (Wittmann et al., 2005) and the prefrontal cortex (Schott et al., 2006).

Aging and Associative Memory

Research suggests that both the PFC and MTL/HPC regions are subject to structural changes throughout the course of the lifespan (Morcom et al., 2010), and many studies that have assessed the relationship between age and memory suggest that normal aging is associated with a decline in episodic memory performance (Floel et al., 2008). As previously mentioned, a key component of recollection is the binding of contextual information to an event, and it has been suggested that older adults are deficient in forming links between content and context (Naveh-Benjamin, Keshet Brav, & Levy, 2007). Research has demonstrated that, compared to younger adults, older adults show decreased activation in the hippocampus during tasks of learning and memory, which may contribute to age-related deficits in binding and episodic memory (Bunzeck et al., 2007).

To test the hypothesis that older adults are impaired in binding information, Naveh-Benjamin et al. (2003) presented pairs of pictures to younger and older adults. All older adults and half the younger adults were instructed to study each pair and prepare for a memory test, whereas the other half of younger adults were instructed to study each pair and complete a simultaneous digit-detection task (divided attention condition). This divided attention condition allowed the researchers to assess whether the age-related deficit in binding items into associations may be due to a reduction in attentional resources. If the age-related memory deficit arises from reductions in attentional capacities, then both younger adults under divided attention and older adults should demonstrate poorer memory performance than younger adults under full attention. Once the study phases were complete, the researchers used two different recognition tasks to assess participants' memory for individual pictures and for pairs of pictures (Naveh-Benjamin et al., 2003). There were no age differences in memory for individual pictures, which suggests that familiarity-based recognition is intact in older adults (Speer & Curran, 2007). However, older adults performed worse on the associative memory task than younger adults in both the full and divided attention conditions. Divided attention affected younger adults' memory performance for item and associative information equally. Thus, younger adults under reduced attentional resources did not show patterns of memory performance similar to older adults, and the researchers concluded that the aging deficit in binding does not arise from an inability to allocate attentional resources (Naveh-Benjamin et al., 2003).

In order to further examine the aging deficit in binding items into associations, the same authors conducted a second study that included word pairs that were and were not semantically related. The results indicated that the age-related associative memory deficit can be reduced when older adults are not required to create new associations between units of information. The established association between semantically related words can facilitate memory of older adults, whereas older adult memory performance is poor when a new association must be formed between two unrelated words. These findings support the hypothesis that older adults are deficient in binding individual items into a cohesive unit (Naveh-Benjamin et al., 2003). In a number of studies that used various versions of the item versus association paradigm, similar age differences have been found for associations between words, word-color, face-face, name-face, and symbol pairs (Naveh-Benjamin et al., 2007, 2009; Salthouse, 1994).

Additional evidence relating to the idea that older adults are deficient in binding is provided by studies that examine event-related potentials (ERPs) associated with the different retrieval processes: familiarity-based recognition and recollection. Research with younger adults has shown that familiarity-based recognition, which does not require the binding of associative details, is associated with an early ERP. Because familiarity-based recognition involves content free retrieval, the associated ERP occurs quickly (approximately 300-500 milliseconds after stimulus onset) and is referred to as the FN400. The FN400 occurs in frontal areas and is more negative for new versus old items. Recollection is a slower, more controlled process than familiarity-based recognition, and it is assessed on tasks of source memory. Source memory tasks require retrieval of contextual details and are associated with a late ERP that occurs about 400-800 milliseconds after a stimulus is presented. This late effect occurs in posterior parietal regions, is more positive for old versus new items, and is referred to as the late old/new effect (Speer & Curran, 2007). Compared to younger adults, older adults demonstrate a reduction in the late old/new effect and poorer source memory performance, whereas the FN400 effect does not appear to be influenced by age (Eppinger et al., 2010).

The behavioral and ERP data from aging studies suggest that, compared to younger adults, older adults can perform just as well on tasks of familiarity-based (item) recognition but are impaired on tasks of recollection and binding. These observed age differences in associative memory might be problematic for optimal functioning in one's everyday environment because the acquisition of simple associative relationships underlie other complex forms of learning, such as reward-based learning (Dickenson, 2001).

Reward-Based Learning and Feedback

Reward-based learning allows for behavioral adaptation to the environment, and it involves the formation of an association between a particular reward and the environmental stimuli that predict it (Savage & Ramos, 2009). In reward-based learning, rewards are positive reinforcers that increase effortful actions; rewards play an important role in organizing and controlling goal-directed behavior (Mell et al., 2005). Reward-based learning is important for the decision-making process because one must choose a course of action from a set of options by evaluating the rewards and punishments that were associated with these options in the past (Marshner et al., 2005).

Reward-based learning processes are driven by prediction error, which occurs when one encounters an unexpected outcome. During learning, an association forms between rewards or punishments and their accompanying contextual stimuli. Positive prediction error includes outcomes that are better than expected and lead to increases in behavior, whereas negative prediction errors include outcomes that are worse than expected and decrease behavior (Bellebaum, Kobza, Thiele, & Daum, 2011). Associative learning models, such as the Rescorla-Wagner (R-W) model, explain how the formation of a simple association is related to reward-based learning (Bray & O'Doherty, 2007; Zellner & Ranaldi, 2010).

The R-W model predicts that only unexpected outcomes support sustained learning. A major element of the model is the degree of surprise, which involves the discrepancy between an expected and actual outcome (Dickenson, 2001; Fletcher et al., 2001). When a particular outcome occurs unexpectedly, other cues in the environment gain associative strength (Mutter et al., 2009), and the model assumes that the associative strength of a cue increases on each learning trial until the outcome is entirely predicted (Dickenson, 2001). If an individual is impaired at forming associations between stimuli, however, then he or she may have a decreased capacity to anticipate outcomes and adapt to environmental demands (Savage & Ramos, 2009).

Role of Dopamine in Reward-Based Learning and Feedback

Reward-based learning is mediated by the dopaminergic neurons in the ventral tegmental area (VTA) of the midbrain (Bellebaum et al., 2011), and can be understood within the context of the R-W model (Bray & O'Doherty, 2007; Tobler, O'Doherty, Dolan, & Schulz, 2005). The dopaminergic activity changes as a function of ongoing events and reflects the degree to which an outcome is different from what is expected. An unexpected reward elicits surprise, a positive prediction error, and increased activity in the dopaminergic VTA, which sends signals to the nucleus accumbens (NAcc) of the ventral striatum (Eppinger, Kray, Mock, & Mecklinger, 2008).

Electrophysiological studies of primates have provided evidence that support these neural correlates of reward processing. Single-cell recordings have shown that the presentation of a rewarding outcome is accompanied by an increase in the firing rate of dopaminergic neurons that project from the VTA to the NAcc (Schultz, 2006). After a reward is no longer surprising, activity in the VTA and NAcc increases when the predictive cue occurs, rather than when the rewarding outcome is presented (Schott et al., 2007).

Additional evidence supporting these neural correlates is provided by fMRI studies that use monetary incentive delay tasks to assess reward prediction and outcome processing of younger adults. In such studies, participants view stimuli that signal the possibility of earning a reward after completing a subsequent number comparison task. Results show that, compared to neutral stimuli, stimuli that predict rewards elicit stronger brain activations in the VTA and ventral striatum (Samanez-Larkin et al., 2007; Schott et al., 2007; Wittmann et al., 2005). Consistent with electrophysiological studies, the results of these imaging studies demonstrate that once learning has occurred, the increased brain activation shifts from the presentation of the rewarding outcome to the time the reward-predicting stimulus is presented (Schott et al., 2007).

Role of Dopamine in Memory Formation

In addition to its connections to the NAcc and other areas of the ventral striatum, the VTA also sends projections to other brain areas, including the frontal cortex, amygdala, and MTL. This network of brain areas, mediated by the dopamine system, underlies reward-learning processes and provides an organism with the ability to flexibly adapt to the environment (Marschner et al., 2005). This dopaminergic system is also important for other cognitive abilities, such as cognitive control, attention, and working memory (Eppinger et al., 2008). In order to examine the age-related differences between associative memory and reward processing, it is important to explore the process of reward-based learning and the role it plays in memory formation.

As mentioned, the hippocampus is important for the ability to form associations in episodic memory, and a number of studies provide evidence that support the idea that this area is essential for encoding novel (Bunzeck et al., 2007) and emotional stimuli (Dougal, Phelps, & Davachi, 2007). Long-term potentiation (LTP) is assumed to be an important process that mediates synaptic plasticity and memory formation within the hippocampus, and research suggests that dopaminergic neurons of the midbrain play a critical role in the induction and maintenance of LTP (Samson, Frank, & Fellous, 2010; Zellner & Ranaldi, 2010).

Research with animals has provided support for the role of dopamine in LTP and memory formation. Encoding novel stimuli is a process that contributes to the induction of LTP, and when monkeys and rats are exposed to novel stimuli, there is increased activity in dopaminergic midbrain neurons that project to the hippocampus (Wittmann et al., 2005). Experiments with rats have shown that antagonists that inhibit dopamine receptors, but not other types of receptors, block the process of LTP and impair maze learning (Düzel, Bunzeck, Guitart-Masip, & Düzel, 2010). It has also been shown in animals that memory for objects and location is disrupted after dopaminergic areas are lesioned (Bäckman et al., 2006).

Additional support for the relationship between dopamine and the hippocampus is provided by studies with human participants. For example, people who are chronic methamphetamine users tend to have decreased dopamine levels, which is associated with impairments in verbal memory (Volkow et al., 1998). The administration of levodopa to healthy adults, however, has been found to facilitate learning and memory of words (Wittmann et al., 2005). Results from fMRI studies have shown that when participants experience novel stimuli, there is increased activation in both the VTA of the midbrain and the hippocampus (Schott et al., 2006). Additionally, the degree of activation in these areas is associated with subsequent memory for such stimuli (Adcock et al., 2006). Given the relationship between dopamine and memory, some researchers have examined the effects of age on the dopaminergic system and reward-based learning (Samanez-Larkin et al., 2007).

Aging and Reward-Based Learning with Feedback

A number of animal, imaging, and postmortem studies have supported the notion that there are age-related changes in the dopaminergic system, which are characterized by declines in dopamine receptors and transporters in the ventral striatum, frontal areas, and the MTL (Bäckman et al., 2006; Marschner et al., 2005). Evidence of age-related changes in the dopaminergic system is also provided by studies that assess performance of younger and older adults on tasks that involve reward-based learning from feedback.

In one such study, Weiler, Bellebaum, and Daum (2008) used a probabilistic reversal-learning task to assess stimulus-reward learning of younger and older adults. Participants were instructed to learn relationships between four symbols and two colors. During the first phase of the learning task, participants were presented with a symbol and were instructed to choose one of two colors. Feedback about the participant's choice was given on every trial: correct responses yielded a monetary reward, and incorrect responses yielded no reward. Throughout the task, the same two symbols were associated with 5¢ while the other two were associated with 20¢. Because of the probabilistic nature of the task, only about 80% of correct responses were reinforced by a reward. In the second phase of the task, the procedure remained the same, except for the fact that the symbol-color associations were reversed. During the third phase, the symbol-color associations returned to contingencies of the first phase, and there was a test phase that did not include feedback. In order to perform accurately in the test phase, participants had to learn that two symbols had consistently been associated with one color and that the symbol-color associations had been switched back to the contingencies of the first phase. Compared to younger adults, older adults demonstrated fewer correct responses and needed more trials to reach the learning criterion. Older adults were impaired in all three phases of the task, which suggests that age negatively affects reward-based associative learning.

The probabilistic reversal learning task used by Weiler and colleagues (2008) requires participants to learn and respond to stimulus-reward associations and use negative feedback to adjust their responses when reward contingencies change (Marschner et al., 2005; Mell et al., 2005; Weiler, Bellebaum, & Daum, 2008). Imaging studies that have used similar paradigms have shown that compared to younger adults, older adults demonstrate poorer performance on these tasks and decreased activation in the ventral striatum in response to reward-predicting stimuli (Marschner et al., 2005; Mell et al., 2005; Weiler et al., 2008). However, learning from negative feedback is important for successful performance on probabilistic reversal learning tasks; other studies of reward-based learning have shown that the ability to learn from positive feedback and anticipation of a gain, rather than negative feedback and anticipation of a loss, remains relatively intact in old age (Eppinger et al., 2010; Samanez-Larkin et al., 2007).

In an aging study that assessed the ways in which positive and negative feedback affected learning, memory, and ERP activity, Eppinger et al. (2010) instructed participants to choose between two visual stimuli presented on a screen. On positive learning trials, correct responses were accompanied by a gain of 5¢ (reward), whereas on negative learning trials, incorrect responses were accompanied by a loss of 5¢ (punishment). Participants were presented with a value of 0¢ (neutral feedback) when they responded incorrectly on the positive trials and correctly on negative trials. Participants then completed a recognition memory test; if they recognized the presented stimulus, they were to indicate whether it had occurred during the positive or negative learning condition. The older adults demonstrated lower learning rates than younger adults across all learning trials, but both older and younger adults had better memory for stimuli presented during positive than negative learning trials.

This memory bias was also consistent with the ERP results; older and younger adults demonstrated an increased FN400 to stimuli that occurred during the positive, but not negative, learning trials, which is consistent with findings supporting the idea that rewards can enhance memory (Adcock et al., 2006). The late old-new effect did not vary as a function of learning trial type, which suggests that positive feedback during learning had an influence on familiarity-based recognition, but not recollection. The late old-new effect did, however, vary as a function of age. On the memory task, younger adults demonstrated a late old/new effect in parietal regions, whereas older adults did not. These ERP findings are consistent with evidence that suggests the aging process negatively impacts binding and recollection more than it does familiarity-based recognition. Perhaps the two age groups rely on different memory mechanisms, but these results suggest that when positive feedback is present, memory performance can be enhanced for both older and younger adults (Eppinger et al., 2010).

Reward Anticipation and Motivated Learning

The ability to learn from positive and negative feedback may be quite different from the ability to anticipate rewards. Research suggests that both processes involve the dopamine system, but reward anticipation is a form of motivated learning that is not driven by feedback (Schott et al., 2007). In reward-based learning, feedback is the mechanism by which an outcome strengthens or weakens the association between a stimulus and a response (Mutter et al., 2009). In reward anticipation, however, extrinsic rewards facilitate learning via motivation, and extrinsic rewards have been shown to enhance motivated learning and memory of younger adults (Adcock et al., 2006).

In an fMRI study that examined the influence of reward anticipation on episodic memory formation, Adcock and colleagues (2006) examined brain activity and memory performance in response to reward cues that preceded a stimulus. Young adult participants in this study were presented with a series of indoor and outdoor scenes that followed either a high ($5) or low (10¢) value reward cue. The reward cue associated with each target indicated the amount that would be earned for accurately recognizing it among distractors during a later test. After each scene was presented, participants completed a visual-motor distractor task in which they indicated the direction of an arrow. Recognition memory was assessed 24 hours later, and participants indicated whether each stimulus was old or new. Next they specified the quality of their memory by responding with a ‘remember’, ‘know’, ‘pretty sure’, or ‘guessing’ response. Ratings did not affect participant compensation, and correct responses resulted in increases in the reward value associated with each target during the study phase. In order to prevent participants from responding ‘old’ to all stimuli, a loss of $2.55 was incurred for all false alarms.

Adcock and colleagues (2006) found that participants remembered more scenes associated with high value reward cues than those associated with low value reward cues. The fMRI results indicated that there was increased activity in the VTA, NAcc, and hippocampus for scenes associated with high value reward cues that were later remembered but not forgotten. Hippocampal activation was related to activity in the VTA, and participants with the greatest activity in these areas demonstrated the most accurate memory for high value scenes, which suggests that rewards can have modulatory effects on the memory formation of younger adults.

In another fMRI study that assessed the relationship between dopaminergic input to the hippocampus, reward anticipation, and episodic memory formation, Wittmann and colleagues (2005) used a monetary incentive delay (MID) task to examine the effects of rewards on memory performance and brain activity of young adults. On a given trial, participants were instructed to respond to a picture stimulus by indicating whether they expected a reward; some participants were told that they could earn money on trials that included a picture of a living thing, and some were told that they would be rewarded on trials that followed a man-made object. After indicating whether or not a reward was expected, participants specified whether a target number was larger or smaller than five. Participants received feedback after every trial, but the task was manipulated so that about 80% of correct responses were followed by a reward. On rewarded trials, a correct response on the number comparison task was followed by a green, upward pointing arrow, which represented a €.50 reward. When participants responded too slowly or incorrectly, they were presented with a red, downward pointing arrow, which represented a loss of €.20. During non-rewarded trials, participants were presented with a question mark, regardless of their accuracy. Participants were then given an immediate memory test and a delayed memory test three weeks later. During the immediate test, participants were shown old pictures from each of the reward cue categories that were presented during the study phase and new pictures that had not been presented previously. During the delayed test, participants were presented with the same stimuli from the immediate test; if participants remembered an item on the delayed test, they were asked to indicate whether it had been presented during the study phase or as a new item during the immediate test phase.

Wittmann and colleagues (2005) found that memory performance was better and reaction times on the number comparison task were quicker for reward-predicting pictures than for neutral pictures. Also during the study phase, compared to neutral pictures, the reward-predicting pictures were related to increased activity in reward-processing areas, such as the dopaminergic midbrain and NAcc. Rewarded outcomes were also associated with increased activation in frontal areas. The results of the delayed memory task indicated that compared to neutral pictures, reward-predicting pictures were associated with increased accuracy for remember versus know/new responses, which reflects better memory for the picture and its context. This supports the idea that reward anticipation can enhance episodic memory that requires the binding of information. Additionally, there was increased activation in the hippocampus and midbrain for reward-predicting pictures that were remembered compared to those that were forgotten. Taken together, the findings from this study support the hypothesis that dopaminergic activity enhances memory formation and retrieval that is dependent upon the hippocampus (Wittmann et al., 2005).

There is some evidence that age-related changes in the dopaminergic system negatively affect reward anticipation of older adults. In one fMRI study, Schott et al. (2007) presented the same MID task used by Wittmann and colleagues (2005) to younger and older adults and patients with Parkinson's disease (PD), which is a disease characterized by a loss of neurons in dopaminergic pathways. During the MID task, younger adults demonstrated increased activation in the ventral striatum and midbrain in response to reward cues associated with positive and negative feedback but not in response to neutral cues associated with a question mark. Younger adults did not show increased activation in these areas when positive feedback signaled a predicted reward. This finding supports the idea that when a rewarding outcome is expected, mesolimbic activity shifts from the time the outcome is presented to the time the predictive cue is presented. For older adults and PD patients, however, reward-predicting stimuli did not elicit increased activation in striatal areas. Instead, older adults and PD patients demonstrated increased activation in the NAcc in response to the positive feedback itself, which suggests that these participants made positive prediction errors of reward. These findings suggest that aging and PD affects one's ability to use cues that predict future rewards, and mesolimbic dysfunction appears to contribute to impairments of reward prediction (Schott et al., 2007). Different results, however, have emerged from other aging studies that have assessed task performance and brain activation during reward and loss anticipation.

In one such study, Samanez-Larkin et al. (2007) found no differences in fMRI activation of the striatum for older and younger adults during reward anticipation. Participants were presented with cues indicating how much money could be earned or lost, depending on how quickly they responded to a subsequent target. The six literal cues used in this study included those that indicated either a gain or loss of $0, 5¢, or $5. When participants responded quickly enough, they earned or avoided losing the particular amount that had preceded the target. Participants were also asked to use a seven-point scale (‘not at all aroused’ to ‘highly aroused’) to indicate their affective responses to each of the cues. The results indicated that during gain anticipation, younger and older adults had similar responses on the self-reported affect and demonstrated similar activity levels in the striatum. During loss anticipation, however, older adults demonstrated less activation than younger adults in brain areas such as the insula and caudate nucleus, and they also experienced less negative arousal than younger adults. These findings suggest that neural activation and subjective responses in anticipation of reward, but not loss, is intact in older adults, which may stem from older adults’ efforts to pay attention to and remember more positive than negative information (Samanez-Larkin et al., 2007).

Other Relevant Research

There are two additional areas of research that are relevant to the discussion of age differences in reward-based learning: emotion regulation and directed forgetting. Emotion regulation research is related to the notion that compared to younger adults, older adults tend to remember more positive than negative information (Mather & Knight, 2005). Presumably, rewards elicit feelings of pleasure and positive emotion, which may be important for reward-based learning. In directed forgetting, participants receive instructions to either remember or forget certain stimuli (Hogge, Adam, & Collette, 2008), which may be analogous to receiving high and low reward cues, respectively. Another topic related to reward-based learning and reward anticipation is personality, and some research suggests that, compared to introverts, extraverts perform better on certain tasks with reward than with punishment (Cohen, Young, Baek, Kessler, & Ranganath 2005).

Aging and emotion regulation.

Research has shown that emotion regulation, which involves the maintenance of one's emotions in a way that maximizes positive affect and minimizes negative affect, improves with age (Mather & Carstensen, 2005). This notion is consistent with research findings from Samanez Larkin et al. (2007), which indicate that older adults respond similarly to younger adults when anticipating rewards but not when anticipating losses. According to the socioemotional selectivity theory, time perspectives influence older adults' goals and motivate them to focus on emotions that are positive rather than negative (Mather & Knight, 2005). The theory predicts that emotion regulation receives greater priority as people age, which is supported by aging studies that use self-report measures. Compared to younger adults, older adults report greater feelings of happiness and less feelings of anxiety or depression (Mather & Carstensen, 2005). Also consistent with this theory, older adults are more likely than younger adults to focus on emotionally relevant stimuli. For example, in one study that explored whether a greater focus on emotion is more likely to change what participants pay attention to, younger and older adults were presented with a dot-probe task. One emotional and one neutral face appeared side by side on a screen for one second. When the faces disappeared, a dot appeared behind one of the faces, and participants indicated the location of the dot. Compared to neutral faces, older adults were slower to indicate which side the dots were on when they appeared behind negative faces and faster when they appeared behind positive faces. The younger adults, however, did not show any attentional biases for the faces (Mather & Carstensen, 2005).

Research has also shown that compared to younger adults, older adults demonstrate better memory performance for positive than negative information. In a study that assessed age differences in free recall and recognition memory for positive, negative, and neutral images, Charles, Mather and Carstensen (2003) found that compared to younger adults, older adults demonstrated better memory for positive than negative images. On a free recall task in which participants were instructed to describe as many images as possible, younger adults recalled the same amount of positive and negative information, whereas older adults recalled more positive images than negative images. Another study examined age differences in decision-making and memory for different health care plans. In this study, Löckenhoff and Carstensen (2007) presented participants with different scenarios that included positive, negative, and neutral information about different aspects of health care, such as preventative care, after-hours care, prescription drugs, appointment availability, and consumer satisfaction. The information was presented in tables on a computer screen so that participants could click on a cell to view its information. Participants were instructed to take as much time as needed to review the information associated with each health care plan and choose one of the scenarios. On a later test, participants were given a printed version of the table; they were asked to indicate which option they had chosen and to fill in the positive, negative, and neutral characteristics for that option. The results showed that older adults reviewed more positive than negative information than did younger adults, and they also recalled the health plans they had chosen as more positive.

Directed forgetting.

Directed forgetting occurs when one attempts to constrain the encoding and retrieval of specific memories. This technique has important implications because it allows for the suppression of irrelevant information. Researchers often use a list method to examine directed forgetting; participants are asked to remember every stimulus that is followed by a ‘remember’ cue and to forget every stimulus that is followed by a ‘forget’ cue. On subsequent memory tests, younger participants demonstrate better recall and recognition for stimuli associated with a remember cue than stimuli associated with a forget cue (Zellner & Bäuml, 2006).

There are two hypotheses that have been developed to explain directed forgetting: the selective rehearsal and attentional inhibition hypothesis. The selective rehearsal hypothesis proposes that participants encode and rehearse ‘remember’ items more so than ‘forget’ items. This hypothesis postulates that when items precede a remember cue, participants encode them more elaborately than items that precede a forget cue. Therefore, ‘remember’ items are more accessible than ‘forget items’ in later tests of memory. Support for this hypothesis is provided by studies that instruct participants to complete an interpolated activity after each cue. Because participants are unable to rehearse each item after it is presented, they show a smaller directed forgetting effect. The attentional inhibition hypothesis suggests that the ‘forget’ cue triggers the process of attentional inhibition, which allows one to suppress irrelevant information and preserve working memory resources (Hogge, Adam, & Collette, 2008; Zellner & Bäuml, 2006).

Successful performance on an item-method directed forgetting task seems to depend on both efficient encoding of ‘remember’ items and inhibition of ‘forget’ items. There is evidence suggesting that older adults are impaired on both types of processes, and many studies have found age differences in directed forgetting. In one such study, Zacks, Radvansky, and Hasher (1996) presented participants with an item-method task. Participants were then instructed to freely recall only items that had been followed by a ‘remember’ cue. Compared to younger adults, older adults recalled fewer words associated with a ‘remember’ cue and more words associated with a ‘forget’ cue. In another aging study of directed forgetting, Hogge and colleagues (2008) instructed participants to read a series of words aloud that were followed by either a ‘remember’ or ‘forget’ cue. During the test phase, the participants were presented with either an ‘old’ or ‘new’ cue accompanied by the stem of a word that appeared in the learning phase. When presented with an ‘old’ cue, participants were instructed to complete the stem with a word that had previously been presented in the learning phase. When presented with a ‘new’ cue, participants were instructed to complete each stem by giving a word that had not been presented earlier. Compared to younger adults, older adults demonstrated a deficit in directed forgetting, which was characterized by a reduction in the recall of ‘remember’ items and an increase in the recall of ‘forget’ items. Taken together, these findings suggest that older adults are impaired at encoding and recollecting ‘remember’ items and are also deficient in inhibiting ‘forget’ items. Age-related impairments in these processes suggest that older adults have less control over memory than do younger adults (Hogge, Adam, & Collette, 2008).

Individual differences and reward.

Some research suggests that individual differences in personality influence performance on tasks of reward learning. Researchers have postulated that reward sensitivity is a main feature of extraversion, and that certain characteristics of extraversion, such as social engagement, positive emotions, and sensation seeking, are by-products of one's sensitivity to reward (Cohen, Young, Baek, Kessler, & Ranganath, 2005). Although there is not a large body of evidence on the relationship between personality and learning, some evidence suggests that one's susceptibility to conditioning is influenced by his or her degree of extraversion and the type of reinforcement that is present (Corr, Pickering, & Gray, 1997). Under threatening or punishing circumstances, introverts have been shown to produce conditioned responses fairly easily, whereas extraverts condition more readily under rewarding conditions (Nagpal & Gupta, 1979). Some researchers have hypothesized that such differences arise from the existence of two basic systems, the behavioral activation system (BAS), which is excited by signals of reward, and the behavioral inhibition system (BIS), which is excited by punishment and the absence of reward. According to reinforcement theory, the BAS and BIS control extravert and introvert behavior, respectively (Depue & Collins, 1999).

Evidence supporting reinforcement theory is provided by studies that assessed verbal operant conditioning in younger adults. In one such study, Gupta and Shukla (1989) presented participants with cards that contained one verb in the past tense and five pronouns (I, We, You, He, They). The participants were instructed to create a sentence using one of the pronouns and the verb on each card. After a pre-conditioning phase, the participants were verbally reinforced with either a reward (‘good’) or punishment (‘poor’) each time they responded with ‘I’ or ‘We’. The results indicated that compared to introverts, extraverts had higher conditioning scores under the rewarding condition and lower conditioning scores under the punishing condition.

Such findings have led some researchers to examine how individual differences affect neural responses to reward processing. In an fMRI study, Cohen and colleagues (2005) examined whether extraversion was related to younger adults’ neural responses to reward. Participants completed a probabilistic gambling task in which they responded to cues by choosing either a low- or high-risk gamble. On low-risk gambles, there was a large chance participants would earn a small reward (80% chance of $1.25 and 20% chance of $0.00), and on high-risk gambles, there was a small chance they would earn a large reward (40% chance of $2.50 and 60% chance of $0). On each trial, participants received feedback on whether they earned money after their choice. The imaging results revealed that compared to trials that were not rewarded, rewarded trials elicited increased activity in reward processing areas, such as the orbitofrontal cortex, amygdala, and NAcc. Furthermore, participants high on extraversion demonstrated significantly higher reward responses in the orbitofrontal cortex and NAcc than did participants low on extraversion. The behavioral results indicated that decision-making strategies did not vary as a function of extraversion, which suggests that the results are mediated by differences in reactivity of the reward system rather than by differences in task performance.

Current Study

The current study aimed to combine the paradigm of Adcock and colleagues (2006) with that of Naveh-Benjamin and colleagues (2003) to assess how reward cues influence the item and associative memory performance of younger and older adults. During the learning phase of the current study, younger and older adults were presented with a series of picture pairs that were preceded by either a 2¢ or 50¢ reward cue. The participants were informed that the reward cue associated with each pair indicated the amount that can be earned if the picture was remembered on subsequent tests. Participant memory for individual pictures was assessed by an item-recognition test in which participants were asked to indicate whether the picture appeared in the learning phase. Associative memory was assessed by a recognition test in which participants were presented with intact pictures belonging to the same pair at study and rearranged picture pairs belonging to different pairs at study; participants were asked to indicate the intact pairs.

Younger and older adults' performance on tests of item- and associative-recognition were compared to determine how reward cues might affect age-related deficits in associative memory processes. It was expected that overall, older adult performance on the item-recognition test would be similar to that of the younger adults (Naveh-Benjamin et al., 2003) and that both age groups would demonstrate high hit rates and low false alarm rates on this test. Given the findings from Naveh-Benjamin et al. (2003; 2007; 2009) that suggest older adults are deficient in binding information, it was expected that overall, younger adults would perform better than older adults on the associative test. Prior aging research has assessed certain aspects of the relationship between reward cues and memory performance, but there is a lack of studies that have examined how reward cues influence the associative memory of younger and older adults. Many aging studies that have examined the effects of reward on brain activity and performance have found that compared to younger adults, older adults demonstrate abnormal brain activations and a decreased ability to use cues that predict future rewards. Consequently, the reward cues in the current study may not have an influence on the associative memory of older adults, and older adults would still be expected to demonstrate an associative memory deficit for stimuli associated with high and low reward cues. Findings from the areas of directed forgetting and emotion regulation can offer additional insight as to why the age-related associative deficit may persist, or alternatively, be reduced under reward cue manipulations.

Findings from directed forgetting studies suggest that older adults have less control over memory processes than younger adults; they recall fewer ‘remember’ items and more ‘forget’ items than younger adults (Hogge, Adam, & Collette, 2008). If the high and low reward cues of the current study are analogous to instructions to ‘remember’ and ‘forget’, respectively, they may have little effect on older adults’ item and associative memory. In contrast, younger adults are able to efficiently encode ‘remember’ items and inhibit ‘forget’ items, so the reward cues should have a maximal effect on their item- and associative-recognition. If younger adults interpret a low reward cue as a ‘forget’ cue and inhibit the stimuli associated with it, they should demonstrate poorer memory for pictures associated with low versus high reward cues on both tests. From this perspective, younger adults were expected to perform better on the associative test in the high versus low reward condition, whereas older adults were expected to perform similarly on the associative test in both reward conditions. Therefore, the age-related associative deficit was expected to be smaller in the low reward condition because of a decrease in younger adult memory accuracy for stimuli associated with low reward cues.

Predictions about the associative performance of younger and older adults were also made on the basis of findings from emotion regulation research. Findings from this area of research suggest that older adults place more emphasis on positive information than do younger adults (Eppinger et al., 2010; Mather & Carstensen, 2005). From this perspective, the reward cues should have an effect on the item- and associative-recognition of both the younger and older adults. For the item test, it was expected that both age groups would have similar performance in both reward conditions; specifically, memory accuracy of both groups was expected to be slightly better for the high than low reward condition. On the associative test, the younger adults were still expected to perform better in the high versus low reward condition, and the same was also expected for older adults. Therefore, the memory performance of both the younger and older adults should be influenced by the high and low reward cues in a way that maintains the age-related associative deficit; as the reward condition changed from high to low, the associative memory performance of both age groups was expected to decrease.

Additionally, because there is research suggesting that, compared to introverts, extraverts respond to and condition more readily with rewarding conditions (Nagpal & Gupta, 1979), it was expected that for both young and older adults, scores on the BFAS would moderate the relationship between reward and memory accuracy on the item and associative tests. Specifically, the relationship between memory accuracy and reward cue on each test may be greater for younger and older adults who score high on extraversion.

CHAPTER 2

Method

Participants

Twenty-four younger adults (ages 18-29) and 24 older adults (ages 60 and above) participated in this study. Younger adults were recruited using the Department of Psychology Study Board at Western Kentucky University and were given partial class credit for their participation. Older adults were recruited by mail using the voter registration database for Bowling Green, Kentucky and from a database containing previous participants and retired faculty from Western Kentucky University. Older adult participants were also recruited via posters placed in various locations throughout the community. All older adults were compensated with a small stipend ($7.50 per hour) for the time that they provided to the study. Prior to entrance into the study, the Telephone Mini Mental State Exam (TMMSE) was used to screen older adults, and all older adult participants of the current study met the passing criterion on the TMMSE. Additionally, all participants were fluent in English and were not taking any medications that could influence cognitive ability. During the study session, a number of individual difference tasks were administered (see Table 1), and basic demographic information, such as age, race, gender, education, SES, and marital status, were also collected from each participant. Each group sample was representative of the community and university populations; gender and ethnicity were of no importance to this study, so participants of both genders and various ethnicities were included.

Table 1

Means and Standard Deviations for Participant Characteristics

Characteristic	Younger	Older
Age (years)	19.79 (2.27)	70.37(6.83)
Education (years)	12.67 (1.05)	15.25(2.58)
WCST Categories Completed**	3.92 (1.32)	2.42 (1.41)
WCST Trials to Complete 1st Category	17.29 (15.10)	21.21 (17.55)
WCST Failure to Maintain Set*	.17 (.38)	.75 (.85)
WCST Perseverative Errors*	5.62 (1.77)	10.25 (6.35)
CAL Retained Responses	19.75 (8.18)	14.46 (10.26)
CAL Forgotten Responses	3.79 (2.78)	3.96 (2.56)
CAL Discrimination Failure	2.58 (2.21)	3.92 (2.84)
CAL Perseveration	1.67 (1.86)	2.92 (3.45)
Reading Span	2.62 (.88)	2.25 (1.19)
WAIS Digit Symbol**	77.08 (10.63)	62.17 (13.91)
WAIS Digit Symbol Incidental Learning*	21.63 (4.67)	16.75 (4.99)
Mill Hill Vocabulary*	30.42 (4.53)	36.74 (8.05)
PANAS Positive**	28.54 (7.50)	37.13 (8.99)
PANAS Negative	13.54 (4.18)	12.22 (2.78)
BFAS Extraversion	74.21 (8.73)	72.58 (10.53)

Note. * $p \leq .01$. ** $p \leq .001$.

Design

This study used a 2 x 2 x 2 mixed design with age (younger vs. older adults) as the between-subjects variable and reward cue (2¢ vs. 50¢) and test type (item vs. associative) as the within-subjects variables. The dependent variable was memory accuracy, which was measured by the proportion of hits and false alarms in item- and associative-recognition tests.

There were two separate study lists, and each list had two versions in order to counterbalance the location of the stimuli (right versus left). Participants were randomly assigned to one of these four lists, and the presentation order of the stimulus pairs in each list was randomized for each participant. The order of the item- and associative-recognition tests was counterbalanced so that half of the participants received the item test first and the other half received the associative test first.

Materials

The stimuli for this study included 264 colored photos of common objects such as *gift, tiger, peach, keyboard, chain, box, radio, refrigerator,* and *drum*, on a white background. These photo objects were obtained from various locations on the internet, including Clipart.com by Getty Images (http://www.clipart.com/en/; Brodeur et al., 2011; Pavio, Yuille, & Madigan, 1968). The 264 photo objects were used to construct two separate study lists. Within each list, the photo objects were paired together randomly to form 68 picture pairs that were not semantically or visually related. Two pairs at the beginning and end of both lists served as buffers, and the remaining 64 photo object pairs constituted the experimental stimuli. There were two different versions of each list so that across the two versions, a particular object appeared on both the right and left side of the picture pair. For example, if *gift* appeared on the right side of a pair in one version, it appeared on the left side of the pair in the other version. Within each list, half of the pairs were randomly assigned to a low reward cue (2¢), and the other half were randomly assigned to a high reward cue (50¢). The study list stimuli were then used to construct target items for the item- and associative-recognition tests. Any particular photo object seen during study appeared in only one of the tests so that the participants were not re-exposed to an item during one of the tests.

Item-recognition test.

The item-recognition test included 24 targets that appeared in the study phase and 24 distractors that did not appear during the study phase. The 24 targets for each list were chosen randomly with the constraint that 12 targets were associated with a low reward cue during study and the other 12 were associated with a high reward cue. No two photo objects from the same pair served as targets in the item test. The distractors for List One included 12 low and 12 high reward photo objects randomly chosen from List Two. Likewise, distractors for List Two included 12 low and 12 high reward photo objects randomly chosen from List One. The presentation order of the targets and distractors was randomized for each participant.

Associative-recognition test.

The associative-recognition test included 24 intact pairs from the study phase and 24 rearranged pairs. The intact pairs were chosen randomly with the constraint that 12 were associated with a low reward cue and 12 were associated with a high reward cue. The rearranged pairs consisted of photo objects from the same reward cue category that were not presented together during the study phase. Specifically, 24 low reward cue photo objects belonging to different pairs at study were recombined to form 12 rearranged, low reward cue pairs. Likewise, 24 high reward photo objects belonging to different pairs at study were recombined to form 12 rearranged, high reward pairs. The presentation order of the intact and rearranged pairs was randomized for each participant.

Procedure

Participants completed the study individually in a single session that lasted approximately an hour and a half. All sessions occurred at Western Kentucky University in the Cognition Laboratory of Gary Ransdell Hall. During the session, participants first completed an informed consent document and a biographical questionnaire, which included questions about education, marital status, socioeconomic and health status, and current medications. Participants were then seated in front of an iMac computer screen for the experimental task. All participants were instructed to study the picture pairs that appeared on the screen in order to prepare for upcoming individual and associative picture tests. Before the learning phase, participants read:

Welcome! In the first part of this task, you will see several pairs of pictures on the computer screen. Please pay close attention to these items and try to remember them because later in the session your memory will be tested. In one type of test, your memory for the individual pictures in the pairs will be tested, and in the other type of test your memory for the two pictures originally presented together in the pairs will be tested. Therefore it is important to pay attention to both the individual pictures and the picture pair.

Before you see each picture pair, you will see a reward cue of either 2¢ or 50¢. These reward cues tell you how much you can earn if you remember the pictures or the *picture pairs on the later memory tests. So, for example, if a picture pair is preceded by a 50¢ reward cue and your memory for that pair is accurate on the later test, you will earn the larger reward. Likewise, if a picture pair is preceded by a 2¢ reward cue and your memory for that pair is accurate, you will earn the smaller reward. Of course, if you don't remember a picture pair, you won't receive either reward.*

Do you have any questions? If so, please ask the experimenter now. When you are sure you understand the task, you may press the spacebar to begin.

At the beginning of each trial, a fixation cross appeared in the middle of the screen for 750 milliseconds. Next, either a low (2¢; grey font) or high (50¢; green font) reward cue appeared for 1500 milliseconds. In an attempt to avoid ceiling and floor effects for the younger and older adults, respectively, the presentation rate was different for the two groups. For younger adults, the picture pair was presented for 3500 milliseconds, whereas for older adults, the picture pair was presented for 5500 milliseconds (Naveh-Benjamin et al., 2003). After all 68 word pairs had been presented, each participant was asked to count backward from 100 by threes for a total of 90 seconds. After this interpolated activity, the two memory tests were administered. In both the item- and associative-recognition test, the presentation of the test stimuli was self-paced. If a participant performed with perfect accuracy on both the item- and associative-recognition test, he or she will earned $12.48.

Item-recognition test.

In this test, participants viewed 48 stimuli, which were presented one at a time on the computer screen. Of the 48 pictures, 24 were target pictures (12 low and 12 high) that appeared in the study phase and 24 were new distractors that did not appear during the study phase. Participants were asked to indicate whether each picture appeared during the study phase by pressing one of two labeled keys on the keyboard. Before the item-recognition test, participants read:

In this part of the task, we would like to see how well you remember the individual pictures from the picture pairs. You will see a series of single pictures in the middle of the computer screen and your job is to indicate whether each one is or is not a picture you saw during the previous study phase. If you remember seeing the picture, press the Y (Yes) key. If you do not remember seeing the picture, press the N (No), key.

Accuracy is more important than speed, so take as much time as you need to make your response. You will not receive feedback on the accuracy of your response during this task, but for each correct response, you will earn the reward that was associated with that picture pair during the study phase. On the other hand, for each incorrect response, you will lose 25¢ from your accumulated reward total. So do try to respond as accurately as possible.

Do you have any questions? If so, please ask them now. When you are sure you understand the procedure, you may press the spacebar to begin.

Associative-recognition test.

The associative test consisted of 24 intact pairs (12 low and 12 high) and 24 rearranged pairs (12 low and 12 high). The 12 low and 12 high intact pairs appeared the same as they did during the study phase, whereas the rearranged pairs consisted of pictures from the same reward cue category that were not presented together during the study phase. Participants were asked to indicate whether each picture pair appeared the same as it did during the study phase by pressing one of two labeled keys on the keyboard. Before the associative-recognition test, participants read:

In this part of this task, we would like to see how well you remember the picture pairs. You will see a series of picture pairs on the computer screen and your job is to indicate whether or not the two pictures in the pair appeared together in the previous study phase.

Some of the picture pairs will contain pictures that did appear together during the earlier study phase and others will contain pictures that did not appear together during study. If you remember seeing the two pictures together in a pair, you should press the key labeled Y (Yes). If you do not remember seeing the two pictures together, you should press the key labeled N (No).

Accuracy is more important than speed in this task, so take as much time as you need to make your response. You will not receive feedback on the accuracy of your response during the test, but for each correct response, you will earn the reward that was associated with that picture pair during the study phase. On the other hand, for each incorrect response, you will lose 25¢ from your accumulated reward total. So do try to respond as accurately as possible.

Do you have any questions about this part of the task? If so, please ask them now. When you are sure you understand the procedure, you may press the spacebar to begin.

Individual differences measures.

After the experimental task, participants were asked to complete a series of tasks that measured various cognitive abilities, such as working memory and executive functioning (Wisconsin Card Sorting Task; Heaton, Chelune, Talley, Kay & Curtiss, 1993 and Reading Span; Salthouse & Babcock, 1991), processing speed (WAIS Digit Symbol; Wechsler, 1997), crystallized verbal knowledge (Mill Hill Vocabulary; Wechsler, 1997), and associative learning and memory (WAIS Digit Symbol Incidental Learning; Wechsler, 1997 and Conditional Associative Learning; Levine, Stuss, & Milberg, 1997). Extraversion and positive/negative affect were also assessed with the Big Five Aspect Scales (BFAS; DeYoung, Quilty, & Peterson, 2007) and PANAS Scales (Watson, Clark & Tellegen, 1988), respectively. All individual difference tasks and scales were used to evaluate whether participants' performance and responses were related to the results of the experimental task. All participants were debriefed, thanked, and awarded the reward amount earned during the item- and associative-recognition test.

CHAPTER 3

Results

For the item- and associative-recognition test, each participant's hit and false alarm rate was calculated for both the low and high reward conditions, which are shown in Table 2. A measure of discriminability (d') for each condition was then computed for each participant. Because the 24 new items were not associated with either a low or high reward value for the item-recognition test, d' scores were computed separately for the low and high reward condition using the hit rate for each condition and the overall false alarm rate. For the associative-recognition test, d' scores were computed separately for the low and high reward conditions with the hit and false alarm rates from each respective condition, and the false alarm rates were based on the 'mismatched' pairs from each reward condition. Two older adult participants were identified as outliers for their group on this test and were excluded from further analyses. These participants were replaced with two new participants, leaving 24 participants in each age group. All analyses were conducted using an alpha level of $p \leq .05$ as the criterion of significance.

Table 2

Means and Standard Deviations for Proportion of Hits and False-Alarm Rates

	Hits		False Alarms	
Test and Reward Cue	Younger	Older	Younger	Older
Item			.02 (.03)	.04 (.05)
Low	.79 (.21)	.82 (.18)		
High	.86 (.13)	.86 (.12)		
Associative				
Low	.81 (.17)	.80 (.19)	.30 (.26)	.47 (.32)
High	.85 (.16)	.82 (.19)	.27 (.29)	.49 (.29)

Means and standard deviations for d’ scores of the younger and older participants for each test type and reward condition are shown in Table 3. Due to differences in the calculation of false alarm rates for the item and associative recognition tests, differences in d’ scores on these tests were assessed using separate 2 (Age) x 2 (Reward Cue) factorial analyses of variance (ANOVA). For the item test, there was a significant effect of reward cue, *F*(1, 46) = 3.90, *MSE* = .28, *p* = .054, η_p^2 = .078, indicating that participants had higher d’ scores for individual pictures associated with high (*M* = 3.30, *SD* = .84) than low (*M* = 3.09, *SD* = .91) reward cues (See Figure 1). There were no age differences in d’ scores on the item test, *F*(1, 46) = .54, *MSE* = 1.28, *p* = .466, and the reward cue by group interaction was not significant, *F*(1, 46) = .70, *MSE* = .28, *p* = .407. For the associative test, there was a significant main effect of group, *F*(1, 46) = 4.23, *MSE* = 3.22, *p* = .045, η_p^2 = .084, indicating that younger adults had higher d' scores (*M* = 2.01, *SD* = 1.51) than older adult (*M* = 1.26, *SD* = 1.18) participants (See Figure 2). There was no main effect of reward cue, *F*(1, 46) = .77, *MSE* = .49, *p* = .386, η_p^2 = .016, and the reward cue by group interaction was not significant, *F*(1, 46) = 1.73, *MSE* = .49, *p* = .195 η_p^2 = .036.

Table 3

Means and Standard Deviations for d'

Test and Reward Cue	Younger	Older	Total
Item			
Low	3.13 (.95)	3.05 (.89)	3.09 (.91)
High	3.43 (.86)	3.17 (.82)	3.30 (.84)
Marginal Means	3.28 (.91)	3.11 (.86)	
Associative			
Low	1.85 (1.47)	1.29 (1.35)	1.57 (1.42)
High	2.17 (1.55)	1.23 (1.01)	1.70 (1.38)
Total	2.01 (1.51)	1.26 (1.18)	

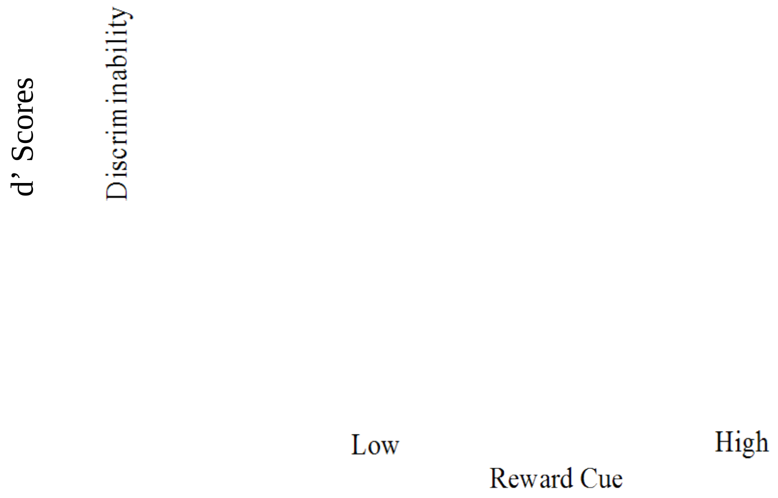

Figure 1. Younger and older adults' mean d' scores for pictures associated with low and high reward cues on the item test.

d’ Scores

Figure 2. Younger and older adults’ mean d’ scores for pictures associated with low and high reward cues on the associative test.

Individual Difference Analyses

Correlational analyses between d’ scores and each individual difference measure were conducted for each test type and reward cue condition. These analyses were conducted separately for each age group, and the results are displayed in Table 4.

Young adults’ perseverative errors on the WCST, which is a measure of executive function, were negatively correlated with d’ scores in the low reward condition for both tests. These correlations indicate that fewer perseverative errors were associated with greater recognition in the low reward conditions for young adults. Young adults’ d’ scores in the high reward condition for both tests were negatively correlated with discrimination failure scores on the CAL, which is a measure of associative learning. Discrimination failures correspond to instances where the participant chose an incorrect response that had been previously confirmed as a correct response for a different stimulus. Therefore, younger adults who had poor discriminability in the high reward conditions were more likely to forget that a particular response had been confirmed as a correct response for another stimulus on the CAL. Additionally, young adults’ Mill Hill Vocabulary scores were positively correlated with d’ scores on the item test in the high reward condition and with d’ scores on the associative test in the low reward condition. These correlations indicate that greater semantic knowledge was associated with greater item-recognition in the high reward condition and greater associative-recognition in the low reward condition. Digit Symbol Incidental Learning scores, which measure incidental associative processing, were also positively correlated with d’ scores in the low reward condition on the associative test. Therefore, an increase in young adults’ incidental associative processing was associated with an increase in their associative-recognition in the low reward condition.

Older adults’ Reading Span scores were positively correlated with d’ scores in both reward conditions on the associative test, indicating that higher working memory performance in older adults was associated with greater associative-recognition in both reward conditions. Digit Symbol scores were also positively correlated with d’ scores in each reward and test type condition, indicating that greater processing speed was associated with increases in older adults’ item- and associative-recognition in both reward conditions. Additionally, older adults’ Mill Hill Vocabulary scores were positively correlated with d’ scores in both reward conditions on the item test. Therefore, an increase in older adults’ semantic knowledge was associated with an increase in their item-recognition. There was also a significant, positive correlation between older adults’ Extraversion scores on the BFAS and d’ scores in the high reward condition on the item test, indicating that an increase in older adults’ extraversion scores was associated with an increase in their item-recognition in the high reward condition. No other correlations between d’ scores and individual difference measures were significant.

Table 4

Correlations Between Discriminability and Individual Difference Measures

	Item Test		Associative Test	
	Low	High	Low	High
Measure	Younger			
WCST Categories Completed	.28	.08	.29	.16
WCST Trials to Complete 1st Category	-.28	-.18	-.33	-.17
WCST Failure to Maintain Set	-.11	-.29	.09	-.07
WCST Perseverative Errors	-.43*	-.05	-.48*	-.38
CAL Retained Responses	.07	.31	.34	.32
CAL Forgotten Responses	.04	-.14	-.22	-.14
CAL Discrimination Failure	-.14	-.53**	-.35	-.45*
CAL Perseveration	-.07	-.08	-.26	-.27
Reading Span	.15	.01	.08	.02
WAIS Digit Symbol	.27	.32	.24	.39
WAIS Digit Symbol Incidental Learning	.30	.15	.44*	.12
Mill Hill Vocabulary	.36	.44*	.54**	.39
PANAS Positive	.25	.17	.15	-.10
PANAS Negative	-.08	.06	-.30	-.17
Extraversion	-.23	-.26	.12	.02
	Older			
WCST Categories Completed	.06	.08	.26	.35

WCST Trials to Complete 1st Category	-.24	-.22	-.32	-.34
WCST Failure to Maintain Set	-.01	-.05	.14	.24
WCST Perseverative Errors	-.08	-.28	-.36	-.33
CAL Retained Responses	.20	.33	.26	.22
CAL Forgotten Responses	-.08	-.08	-.07	-.34
CAL Discrimination Failure	-.10	-.24	-.35	-.07
CAL Perseveration	-.16	-.25	-.19	-.14
Reading Span	.37	.16	.50*	.67**
WAIS Digit Symbol	.51*	.48*	.45*	.53**
WAIS Digit Symbol Incidental Learning	.02	.27	.28	.38
Mill Hill Vocabulary	.55**	.42*	.34	.26
PANAS Positive	.09	.33	.13	.01
PANAS Negative	-.30	-.32	-.13	-.08
Extraversion	-.03	.41*	.01	.00

Note. **p* < .05. ***p* < .01.

We were interested in examining whether the relationship between reward cue and discriminability on each test might be greater for younger and older adults who have high extraversion scores. However, extraversion scores were not significantly correlated with younger or older adults' d' scores on the associative test so a 2 (Age) x 2 (Reward Cue) x 2 (Extraversion) factorial ANOVA was conducted only for the item-recognition d' scores. Because younger and older adults did not have identical distributions for the extraversion scores, a median split of extraversion scores for each age group was used to determine whether a participant in the respective age group was low or high on extraversion. Means and standard deviations for d’ scores of the younger and older participants for each reward condition and extraversion group are shown in Table 5.

Table 5

Means and Standard Deviations of d' Scores as a Function of Reward Cue and Extraversion

Reward Cue and Extraversion	Younger	Older	Total
Low Reward			
Low Extraversion	3.47 (.95)	2.96 (.87)	3.22 (.93)
High Extraversion	2.78 (.86)	3.13 (.94)	2.96 (.90)
High Reward			
Low Extraversion	3.63 (.90)	2.86 (.73)	3.24 (.89)
High Extraversion	3.23 (.80)	3.49 (.81)	3.36 (.80)

The 2 x 2 x 2 ANOVA revealed a significant effect of reward cue, *F*(1, 44) = 4.02, *MSE* = .27, *p* = .051, η_p^2 = .084, indicating that participants had higher d’ scores for individual pictures associated with high (*M* = 3.30, *SD* = .84) than low (*M* = 3.09, *SD* = .91) reward cues, which is in line with the results of the ANOVA conducted previously without Extraversion as an independent variable. The Reward Cue x Age x Extraversion interaction was not significant, *F*(1, 44) = .15, *MSE* = .27, *p* = .703, but there was a marginally significant Reward x Extraversion interaction, *F*(1, 44) = 3.16, *MSE* = .27, *p* = .082, η_p^2 = .067. Although this was not a significant result, the general trend suggests that there was no change in performance between the high and low reward conditions for participants who were low on extraversion, whereas participants who were high on extraversion performed slightly better in the high versus low reward condition (See Figure 3).

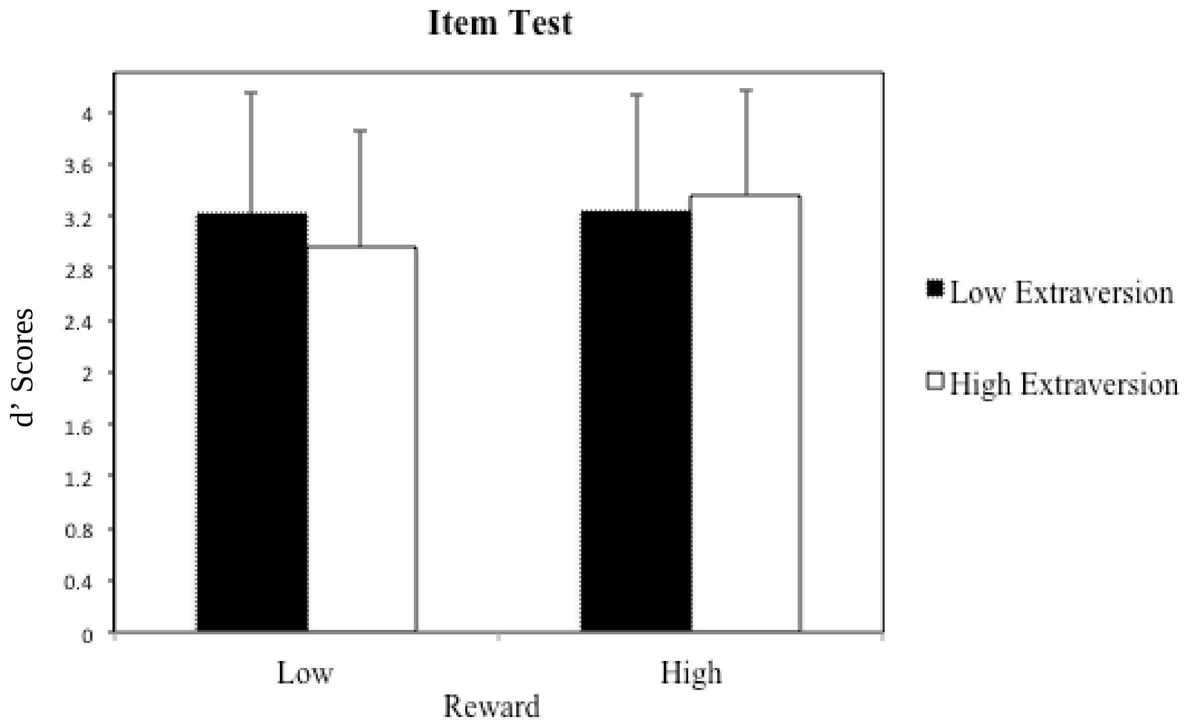

Figure 3. Mean d' scores for participants in each extraversion group across both reward conditions on the item test.

As expected, there were no age differences in d’ scores, *F*(1, 44) = .57, *MSE* = 1.21, *p* = .45, and the Reward Cue x Group interaction was not significant, *F*(1, 44) = .72, *MSE* = .27, *p* = .40. There was not a significant effect of Extraversion, *F*(1, 44) = .09, *MSE* = 1.21, *p* = .76, but there was a significant Group x Extraversion interaction, *F*(1, 44) = 4.40 *MSE* = 1.21, *p* = .042, η_p^2 = .091. An analysis of the simple effect of age at low extraversion showed a main effect of age, *F*(1, 46) = 6.56, *MSE* = .75, *p* = .014, η_p^2 = .125, indicating that younger adults had better discriminability (*M* = 3.55, *SD* = .93) than older adults (*M* = 2.91, *SD* = .80). The analysis for the simple effect of age at high extraversion was not significant, *F*(1, 46) = 1.50 *MSE* = .73 *p* = .227, indicating that there were no age differences in discriminability between younger (*M* = 3.01, *SD* = .83) and older adults (*M* = 3.31, *SD* = .87) who were high on extraversion (See Figure 4).

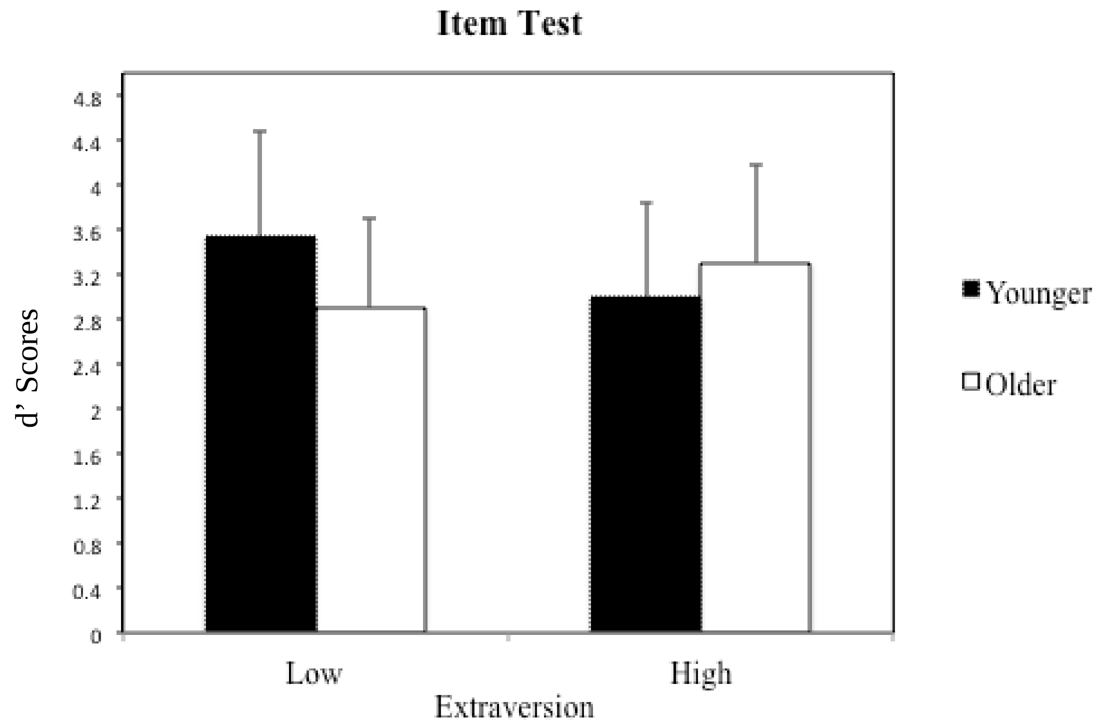

Figure 4. Overall mean d' scores for younger and older adults in each extraversion group on the item test.

CHAPTER 4

Discussion

The current study aimed to examine how reward cues influence the item and associative memory performance of younger and older adults. On the item test, it was predicted that older adults would perform similarly to younger adults and that both age groups would have better memory for individual items associated with high versus low reward cues. This prediction was confirmed. The results revealed that older adult performance on the item-recognition test was similar to that of younger adults. This finding is consistent with the predicted result regarding age for the item test and is in line with findings in the literature (Naveh-Benjamin et al., 2003). The results also revealed that younger and older adults demonstrated better discriminability for pictures associated with high versus low reward cues. This finding is consistent with the predicted result for the item test and is in line with previous research showing that reward cues have modulatory effects on item memory (Adcock et al., 2006)

On the associative test, it was expected that there would be age differences in associative memory. The results revealed that younger adult performance on the associative-recognition test was better than that of older adults, which provides further support for an age-related associative deficit and is consistent with previous findings in the literature (Naveh-Benjamin et al., 2003). There were two different predictions that were made regarding the influence of reward cues on the associative memory of younger and older adults. One made on the basis of findings from emotion regulation research (Mather & Carstensen, 2005), suggested that both age groups would be influenced by the reward cues in a way that maintained the age-related associative deficit. Specifically, it was predicted that the associative memory performance of both age groups would be better in the high than in the low reward condition. The other, made on the basis of findings from directed forgetting research (Hogge, Adam, & Collette, 2008), predicted that younger adults would perform better on the associative test in the high versus low reward condition, whereas older adults would perform similarly on the associative test in both reward conditions. Consequently, the age-related associative deficit was expected to be smaller in the low reward condition because of a decrease in younger adult memory accuracy for pictures associated with low reward cues. Neither of these predictions was supported by the results; there was no difference in associative-recognition for pictures associated with high versus low reward cues for either age group.

Reward Cues and Memory

Although the predictions regarding reward and performance on the associative-recognition test were not supported, the overall findings have important implications for age-related changes in memory and reward processing. We have replicated two findings from age-related memory research: memory for individual items is intact in older adults, but there is an age-related deficit in binding and associative memory (Naveh-Benjamin et al., 2003). Additionally, we have replicated and extended the results of Adcock and colleagues (2006). Specifically, like Adcock et al.'s young adults, our younger adults' memory was better for individual stimuli associated with high versus low reward cues, and we have further demonstrated that high reward cues can also enhance older adult memory for individual items. Although some research suggests that reward processing and reward-related brain activity is diminished in older adults (e.g. Schott et al., 2007), the current results are consistent with studies showing that reward-related item learning and gain anticipation are intact in older adults (Eppinger et al., 2010; Samanez-Larkin et al., 2007).

Findings from a number of animal, imaging, and postmortem studies have suggested that aging is accompanied by declines in dopamine receptors in reward-processing brain areas (Marschner et al., 2005). Some evidence suggests this general decline does appear to negatively affect older adults' ability to learn and respond to stimulus-reward associations that require learning from positive and negative feedback (Weiler et al., 2008). Although the findings of this study are strictly behavioral, it appears that aging, and possibly any age-related declines in reward-related brain areas, does not negatively impact the ability to utilize reward cues on a simple task of item-recognition. This notion is consistent with the finding that both younger and older adults demonstrate similar brain activations and have better memory for stimuli associated with gains versus losses (Samanez-Larkin et al., 2007).

Another possible explanation as to why the reward cues enhanced the item memory of younger and older adults could be that the high reward cues increased the distinctiveness of the stimuli more so than the low reward cues. There are a number of ways to vary the degree of item distinctiveness, such as displaying pictures versus words, presenting visual versus auditory stimuli, presenting words in different versus the same font, and instructing participants to note unique versus similar aspects between two stimuli. The general finding from this area of research is that the more distinctive the item, the better it is remembered on later tests of item memory (Arndt & Reder, 2003). In this way, high reward cues appear to modulate younger and older adults' attentional focus and increase item distinctiveness in memory, which can lead to better recognition of items.

Even though both age groups of the current study were better able to remember the items that were associated with larger gains, the reward cues had no such effect on the associative memory performance of younger and older adults. This particular finding was unexpected, especially because there is some evidence supporting the idea that reward cues might have an effect on associative memory. For example, although Adcock and colleagues (2006) did not assess associative memory, they found that brain activity in reward-processing areas and the hippocampus was increased when participants viewed stimuli associated with high reward cues that were later remembered. This finding suggests that there is a relationship between reward anticipation and episodic memory formation and is consistent with the behavioral finding that participants tend to remember individual stimuli associated with high value reward cues better than those associated with low value reward cues. Given the evidence supporting a relationship between binding, the hippocampus, and reward-processing areas of the brain (Wittmann et al., 2005), it was surprising that the reward cues of the current study did not have an effect on younger and older adults' associative memory.

Although it is not exactly clear why the reward cues had modulatory effects on item but not associative memory, there are some lines of research that may provide insight into this difference. First, ERP studies that assess learning across trials have provided some evidence that reward has an effect on item, but not associative, memory. For example, Eppinger et al. (2010) found that both younger and older adults had better memory for stimuli presented during positive than negative learning trials. In addition, their ERP data showed that positive, but not negative, learning trials were associated with an increase in the early old-new effect during retrieval, which corresponds to familiarity-based recognition processes. While familiarity-based recognition and the early old-new effect are associated with fast and automatic retrieval processes, the late old-new effect is associated with recollection, which is a slower, more deliberate process that tends to require binding of two items, or an item and its context, during encoding. Eppinger et al. (2010) found that the late old-new effect did not differ between the positive and negative learning trials. In a similar vein, it may be the case that the reward cues in this study had a greater impact on familiarity-based recognition than on the more deliberate recollection processes in associative recognition (Eppinger et al., 2010).

A second area of research that might explain why the reward cues did not affect associative memory involves item distinctiveness. As mentioned previously, it is possible that the high reward cues increased the distinctiveness of the items. There is evidence that item distinctiveness impacts familiarity-based recognition and associative recognition differently. Although studies examining the impacts of distinctiveness on item recognition have shown that distinctive items are better remembered than items that are less distinctive, the opposite pattern is often found for associative recognition. For example, in one study examining the effects of word frequency on item and associative memory, Clark (1992) presented participants with study lists that included either all high or all low frequency word pairs. Participants were then given tests of item recognition, associative recognition, and free recall. The results of the item recognition test indicated that distinctive, low frequency words were remembered better than high frequency words. On the contrary, less distinctive, high frequency words were remembered better than distinctive, low frequency words on the tests of associative memory and free recall (Clark, 1992). Therefore, it appears that increasing stimulus distinctiveness enhances item recognition but not associative recognition, which is consistent with the current findings. The high reward cues increased the distinctiveness of individual pictures and modulated participants' attentional focus more so than the low reward cues. The increase in distinctiveness led to better recognition of individual pictures associated with high versus low rewards, but it did not enhance participants' associative recognition.

There are also a number of methodological issues that may have influenced the size of the reward cue effect on associative memory. One is the fact that we examined long-term memory after a short, rather than a long, retention interval. The short retention interval might have minimized any differences between the high and low reward cues. Therefore, it is possible that we might observe an effect of reward on associative memory if we assess participants' memory after a longer retention interval. On the other hand, increasing the retention interval could produce a floor effect in older adults', and possibly young adults', memory performance on the associative test. Future studies should examine whether various retention intervals might reveal an effect of reward on both item and associative memory. Another methodological issue may be that the difference between the two reward values was not large enough to impact associative memory. Future studies could address this issue by examining differences in item and associative memory for reward versus no reward or for reward versus punishment. Perhaps a larger difference between the reward cues would produce an effect on associative memory, even if a short retention interval is used. A third methodological explanation for why the reward cue effect was not evident in associative memory is the structure of the associative test itself. On the item test, distractors were new items that were never associated with a reward during the study phase. However, on the associative test, distractor pairs were composed of stimuli that had been associated with reward cues during study. Given the evidence suggesting that the high reward cues increased the distinctiveness of the individual items, we can assume that both the high reward targets and high reward distractors in the associative test were also more distinctive than those associated with low reward. Consequently, the reward effect may have been undetectable on the associative test because the high reward targets were no more distinctive than the high reward distractors.

The paradigms used in studies conducted by Naveh-Benjamin and colleagues (2003; 2007) closely resemble the one implemented in the current study, so it is important to compare the current results with those from other studies that aimed to reduce the age-related associative deficit. Findings from such studies suggest that older adults' associative memory can be enhanced by some experimental manipulations. In one study, Naveh-Benjamin et al. (2007) presented unrelated word pairs to younger and older adults and instructed some participants from each age group to create a sentence between the unrelated words in each pair. The results indicated that younger adult performance on the item and associative tests was about the same, regardless of whether they were instructed to use the encoding strategy. However, older adults who were instructed to use the encoding strategy performed better on both tests than those who were not given additional instructions. This suggests that encoding strategies involve increased elaboration and binding, which lead to improvements in older adults' associative recognition. Although the current results suggest that high reward cues enhance distinctiveness and participant memory for items, the reward cues did not lead to increased elaboration or binding. Therefore, the encoding strategies in the study conducted by Naveh-Benjamin et al. (2006) were more effective in reducing the age-related associative memory deficit than the reward cues of the current study.

Extraversion, Reward Cues, and Memory

The current study also aimed to examine the relationship between discriminability, reward cues, and extraversion. Given that extraversion scores from the BFAS were not significantly correlated with either age groups' d' scores on the associative recognition test, analyses were only conducted for the item recognition test. We predicted that the relationship between d' scores and reward cue would be greater for all participants who scored high on extraversion, but this hypothesis was not supported. Other research has demonstrated a difference in the way that extraverts and introverts respond to reward; extraverts tend to condition more readily under rewarding conditions, whereas introverts tend to condition more readily under threatening or punishing conditions (Nagpal & Gupta, 1979). In the current study, the participants were informed that they would lose a certain amount of their reward total for every incorrect answer, but there was no feedback to inform the participants about the accuracy of their response. Perhaps we would have observed a moderating effect of extraversion if we had explicitly included punishment as part of the study's design.

Interestingly and unexpectedly, the results did indicate that the relationship between d' scores on the item test and extraversion varied by age group. Low extraversion younger adults had better discriminability than low extraversion older adults, whereas there were no age differences in discriminability for high extraversion younger and older adults. This difference suggests that at least for older adults, high extraversion may be associated with better memory for individual items. Some researchers have suggested that positive emotion, social engagement, and life satisfaction may stem, in part, from where one falls on the extraversion-introversion continuum. Specifically, people who are highly extraverted tend to report being happier and find more enjoyment out of social situations than do those who are highly introverted (Cohen et al., 2005). Older adults who are extraverted tend to have a more enriched lifestyle than those who are introverted, and this may have positive effects on memory and other cognitive abilities. For example, Meier, Perrig-Chiello and Perrig (2002) examined the influence of extraversion on individual differences in older adults' memory for complex scenes. The results indicated that high extraversion was associated with better memory performance than low extraversion. Additional research should be conducted on this topic in order to better understand the factors that might underlie this group difference.

Summary and Conclusion

In conclusion, the results of this study join those from previous research demonstrating that item memory is intact in older adults and that there is an age-related associate deficit that stems from older adults' inability to bind two items into a cohesive unit (Naveh-Benjamin et al., 2003). The study also confirms the previous finding that younger adult item memory can be enhanced by high reward cues (Adcock et al., 2006) and extends this result by showing that it also applies to older adults. Despite the modulatory effects of reward on younger and older adult item memory, the findings do not support the notion that memory for associations can be enhanced by the same rewards. One theoretical explanation that might explain the difference between these types of memory is that higher rewards increase stimulus distinctiveness, which enhances participants' familiarity-based recognition of items, but not recollection of associations. Another explanation is that certain aspects of the experimental design may have reduced our ability to measure reward cue differences in the associative recognition test. These issues should be addressed in future research in order to better understand the impact of reward cues on the item and associative memory of younger and older adults.

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