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Associative and Error-Driven Learning in Younger and Older Adults

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ASSOCIATIVE AND ERROR-DRIVEN LEARNING IN YOUNGER AND OLDER
ADULTS

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Candice B. T. Groves

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ASSOCIATIVE AND ERROR-DRIVEN LEARNING IN YOUNGER AND OLDER ADULTS

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TABLE OF CONTENTS

ASSOCIATIVE AND ERROR-DRIVEN LEARNING IN YOUNGER AND OLDER ADULTS

Candice Brooke Tucker Groves   December 2011   Pages 52

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Previous research has consistently shown associative deficits in older adults learning and memory (Chalfonte & Johnson 1996; Naveh-Benjamin, 2000; Naveh-Benjamin, Hussain, & Bar-On 2003) that are related to decreases in hippocampal function (Driscoll et al., 2003; Mitchell, Johnson, Raye, & D'Esposito, 2000). However, older adults learn certain simple predictive relationships between events (Mutter & Williams, 2004) that involve basal ganglia dependent error-driven learning. The goal of the current study was to determine whether error-driven learning could reduce the age-related associative deficits that are associated with hippocampal decline. The results did not support the idea that error-driven learning enhanced older adults' associative memory, although our study supported normal error-driven processing in older adults. Our study confirms prior findings showing that age differences in associative memory are greater following an error-driven learning task than following an observation learning task (Schmitt-Eliassen, Ferstl, Wiesner, Deuschl, & Witt, 2007; Shohamy et al., 2004). Therefore, the results of the study did not support enhanced associative memory for older adults due to error-driven processing.

ASSOCIATIVE AND ERROR-DRIVEN LEARNING IN YOUNGER AND OLDER
ADULTS

Considerable research has shown that episodic memory is the type of memory most affected by the aging process. Episodic memory combines the what, when, and where of an event in memory. These types of memories are associative in nature and require binding of contextual information to the event in order to enhance recollection.

Several studies have supported the idea that older adults' episodic memory deficits reflect an underlying binding deficit (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000). These studies have included item-item binding, item-feature binding, and item-context binding. It is also well documented that the hippocampus is important for binding information into unitary memories. Rat studies have shown hippocampal lesioned rats cannot retrieve bound information previously learned before lesioning (Ergorul & Eichenbaum, 2004). Human studies have shown increased activation indicative of successful encoding and retrieval for bound word pairs and face-name pairs (Jackson & Schacter, 2004; Kirwan & Stark, 2004). Not only do studies indicate a binding deficit, which is reported to reflect hippocampal function, but there are also studies that report the structural and biochemical changes that occur in the hippocampus during normative aging. Structural changes include a decrease in hippocampal volume thought to be due to neuronal loss (Driscoll et al., 2003; Kramer et al., 2007). Biochemical changes in the hippocampus include a decrease in NAA/Cre values (Driscoll et al., 2003). NAA metabolite is important in developing and maintaining white matter; and Cre levels are important for supplying energy to the brain in the ATP process. Johnson and colleagues have also found decreased hippocampal activation for older adults during a binding or associative task (Mitchell, Johnson, Raye & D'Esposito, 2000).

1

These results suggest that the normal changes that occur in the hippocampus may be responsible for the binding deficit seen in older adults.

It is clear that older adults have difficulty forming associative memories that depend on intact hippocampal functioning. However, other research shows that older adults do acquire some types of associations. In particular, during predictive or causal learning tasks, older adults acquire simple generative associations as readily as young adults (Mutter, DeCaro & Plumlee, 2009; Mutter, Haggbloom, Plumlee & Schirmer, 2006; Mutter & Williams, 2004; Parr & Mercier, 1998). This raises the question of why older adults can learn simple generative associations during predictive tasks but have trouble learning simple associations between events in tasks that involve associative binding. One possibility is that while the hippocampus is involved in both associative binding and predictive tasks, the basal ganglia are engaged during the error-driven learning processes that occur during predictive learning tasks.

Error-driven learning makes actions followed by positive outcomes more likely to occur and those followed by negative outcomes less likely to occur (Holroyd & Coles, 2002). Neural error-related negativity signals after an incorrect response are associated with correcting the response and keeping the error from occurring again.

A study with Parkinson's patients has shown that error-driven learning requires intact basal ganglia (Shohamy et al., 2004). Some research suggests that error-driven learning, mediated by the basal ganglia may also be reduced in older adults. Studies have found reduced ERNs for older adults compared to young adults on a probabilistic task (Niewenhuis et al., 2002). However, Eppinger, Kray, Mock and Mecklinger (2008) pointed out that not only were older adults' ERNs reduced but their performance levels

were also reduced. Eppinger and colleagues (Eppinger et al., 2008) found similar ERNs and performance levels for 100 and 50 % outcome validity conditions in the probabilistic task when learning conditions were equated. However, the 80 % outcome validity condition yielded age differences. These results suggest that validity of outcome or feedback is important for older adults' learning. Older adults are able to learn cue-outcome associations, but invalid feedback seems to interfere with this ability. Other studies support the idea that there are no age-related deficits in error processing (Friedman, Nessler, Cycowicz & Horton, 2009; Samanez-Larkin et al., 2007).

The current study examined young and older adults' performance on associative and error – driven learning tasks to determine whether error-driven learning processes could reduce age-related deficits in associative processes. Although the results of this study support normal error-driven learning processes in older adults, they do not support the idea that error-driven learning enhances older adults' associative memory. Learning performance was similar for younger and older adults in the error-driven learning task, which supported Eppinger et al.'s (2008) findings. Age differences in associative memory were expected to vary as a function of learning task and validity. For the 100 % outcome validity condition, older adults were expected to perform similarly to younger adults following the error-driven learning task, and worse following the observation learning task. In the 75 % validity condition, younger adults were expected to outperform older adults on both learning tasks due to the probabilistic structure of the task. In the 50 % condition, no age differences were expected due to the random feedback the participants received. The results revealed that, except for the 50 % validity condition, older adults' overall memory performance was worse than younger adults following the

error-driven learning task, but performance was similar for the two age groups following the observation learning task. Therefore, the expected result of age differences varying as a function of the combination of learning task and validity were not obtained.

However, age differences in memory did vary as a function of the combination of validity and test type, which was not predicted. In the 100 % outcome validity condition, older adults' overall performance across the two types of associative memory tests was worse than younger adults' and performance for both groups was lower for the recall test than the prediction test. For the 75 % condition, older adults performed worse on the recall test than younger adults, but their performance was similar on the prediction test. In the 50 % condition, prediction test performance was better than recall test performance due to different chance probabilities, but overall retrieval performance was poor because there was no valid outcome. Age did not play a role in this condition.

Older adults' worse memory performance than younger adults' following the error-driven task suggests that although no age differences were present during the error-driven learning task, this task was not as effective for older as for younger adults. Similar to my study, Schmitt-Eliassen and colleagues' (Schmitt-Eliassen et al., 2007) study showed age differences during a prediction test, but not during prediction learning. Retrieval test findings for my study also disputes the idea that older adults are more affected than younger adults by probabilistic structures. The presence of age differences for the 100 % outcome validity condition combined with the lack of age differences for the 75% validity condition on the prediction test actually suggests that younger adults' performance was more affected by outcome uncertainty than older adults'. Overall, the results of the study did not support enhanced associative memory for older adults due to

4

error-driven processing. Further research should be conducted to help clarify the role of learning task and test type on associative memory performance, as well as distinguish differences between error-driven learning and subsequent retrieval processes following this type of learning.

CHAPTER 1

Literature Review

Considerable research shows that episodic memory is the type of memory that is most affected by the aging process. Episodic memory combines the what, when, and where of an event in memory. For example, when remembering where you left your keys you must remember what you were doing, where you were, and when you had your keys last to remember where your keys are presently. These types of memories are associative in nature and require binding of this contextual information to the event in order to enhance recollection.

Aging, Associative Learning and Memory

Chalfonte and Johnson (1996) thought older adults' episodic memory deficits were due to an underlying binding deficit. To test their binding theory, they gave younger and older adults information that required them to bind contextual information with a presented item. However, first they needed to establish baseline performance for individual features, including items, locations, and colors that did not require participants to bind information. In this test they found that older adults had a memory deficit for location, but their memory performance for item and color was similar to that of younger adults. According to Johnson and her colleagues, if no deficits in binding are present,

older adults should perform as well as young adults on a task requiring them to remember an item and its color.

To test for binding deficits, younger and older participants were presented with colored items and asked to remember either the color or the item and its color. Then all of the participants were given a recognition test for the items and their corresponding colors. When the instructions were to study only the color, older and younger adults both performed poorly on the recognition task for color and item. However, when the instructions were to study both the item and its color, younger adults' performance was much higher than older adults' performance. The older adults' performance was low, regardless of the instructions. These results supported the binding deficit hypothesis because although older adults performed like young adults for individual features of item and color, their performance was much lower for the combination of item and color. Older adults do not recall information as well when the features of the memory need to be bound, even when told specifically to study both features. Thus, older adults' memories for bound memories (item and color) appear to be more impaired than their memory for individual features.

Naveh-Benjamin (2000) added to Johnson and colleagues (Chalfonte & Johnson, 1996) idea that binding deficits are responsible for poor memory performance in older adults. Naveh-Benjamin's "associative deficit hypothesis" states that most of older adults' memory deficits come from their difficulty in binding information into a unitary memory representation. Binding can occur for two items, an item and its context, an item and its features, or between features. Naveh-Benjamin has conducted numerous studies that show support for this binding or associative deficit in older adults (Kilb & Naveh-

Benjamin, 2007; Naveh-Benjamin, 2000;; Naveh-Benjamin, Guez, Shulman, 2004; Naveh-Benjamin, Hussain, Guez & Bar-On, 2003). In one study, Naveh-Benjamin (2000) tested recognition for item-item binding. Young and older participants were presented with pairs of words and were instructed to either study the individual words for an upcoming item recognition test or the pairs of words for an upcoming associative recognition test. Then participants were given either an item recognition test or an associative recognition test for the pairs of words. In the item recognition test, participants were shown study words as well as distracter words and were to choose which words were presented in the study. In the associative recognition test, participants were shown intact pairs of words from the study list as well as distracter pairs and were to choose which pairs were presented in the study phase. The results for the item test showed that older adults' recognition performance was slightly lower for the individual words than younger adults' performance even if they were instructed to study the words individually. For the associative test, young adults outperformed older adults. However, young and older adults' performance also differed due to instructions for the associative test. Younger adults' performance depended on the instructions they were given. When they were instructed to study the individual words, they performed more poorly than when they were told to study the word pairs. However, older adults' performance for the associative test was poor regardless of the instructions they were given and was also lower than their performance for the individual items. Therefore, compared to young adults, older adults showed poorer performance for recognition of associative information than item information. These findings support the notion that there is specifically an associative deficit responsible for memory deficits seen in older adults.

In another experiment (Naveh-Benjamin, 2000), recognition memory was assessed for an item and its context. Participants were presented with individual words varying in font and were instructed to study the words, the fonts, or the words and their corresponding fonts for an upcoming recognition test. When given a word recognition test, younger and older adults performed equally well regardless of the instructions they were given. For the font test, performance decreased but was similar for younger and older adults, regardless of the instructions they were given. However, for the associative test (word and font), older adults' performance was much poorer than younger adults, regardless of the instructions they were given. The results provided further support for the associative or binding deficit in older adults, since older adults had trouble remembering the association between the word and the font, but not the font or word individually.

The associative deficit hypothesis was also supported by findings from another study (Naveh-Benjamin, 2000), in which semantically related and unrelated word pairs were recalled or recognized. Related or unrelated word pairs were shown to participants and they were instructed to study both the individual words and the words as a pair. Then the participants were given a free recall test, a cued-recall test, or an associative recognition test for the word pairs. The results showed that older adults had more difficulty remembering unrelated words as a pair compared to related words, regardless of the testing method. Again, these findings are in support of the hypothesis because the preexisting association between the semantically related words facilitated memory for those word pairs. With the unrelated word pairs, older adults performed more poorly because they had to establish an association between the words.

Other research by Naveh-Benjamin and colleagues has further defined the nature of older adults' associative or binding deficit. Naveh-Benjamin et al. (2003) showed that the associative deficit occurred with pictures as well as words. In addition, the associative deficit is not a function of age-related decline in attentional resources (Kilb & Naveh-Benjamin, 2007; Naveh-Benjamin et al., 2004; Naveh-Benjamin et al., 2003). For example, Kilb & Naveh-Benjamin (2007) asked young and older adults to study lists of words either with full or divided attention. The results showed no associative deficit for younger adults under divided attention. Older adults' associative deficit also did not increase under divided attention. Therefore, divided attention did not cause greater detriment to either group's performance on an associative task. Since declining attentional resources are not to blame, there must be another reason for this binding deficit.

Binding and Hippocampal Function

It is well documented that the hippocampus is important for binding information into unitary memories. Human and animal studies support this idea. For example, rats use the combination of spices and their locations to learn about temporal order much like humans use contextual information to learn associative information (Ergorul & Eichenbaum, 2004). In the training portion of a study by Ergorul and Eichenbaum (2004), rats were presented with cups of scented spices in varying locations. The cups were presented one at a time in a specific location and the rats could dig through the cups and find a reward. During the testing phase, the rats were shown two cups at a time in their originally presented locations. However, only the cup presented earliest in the training phase contained the reward. So in order to perform accurately, the rats had to remember

which cup of spice was presented first in order to select it and find the reward. The rats performed significantly above chance levels of 50% correct and no lower than 61.9 % correct for any combination of choice pairs. After the training and testing, half of the rats received bilateral hippocampal lesions. The control rats' performance on the task was again, significantly above chance, but the performance of rats with hippocampal lesions was not. The lesioned rats showed a tendency to go back to the most recently rewarded location/cup. These results show that the hippocampal lesioned rats could not retrieve the combined spatial and odor cues in order to recall when the trial occurred.

In a follow-up study using the scented spice cup procedure, Komorowski, Manns, and Eichenbaum (2009) showed activation in the hippocampus for item-context associations. In this study, rats explored two contexts that varied in their flooring and walls, and had to determine which of two cups that varied in color and scent contained a reward. In context A, cup X had the reward and in context B, cup Y held the reward. The results from neuron signaling measures showed that hippocampal neurons in CA1 and CA3 regions were activated for the context -event information learned. In these regions, item-position cells developed which preferentially fired for a specific item and position. The activity of the item-position cells predicted the accuracy of the response with more item-position activity being indicative of higher accuracy. Therefore, the study suggests that hippocampal activation supports context-bound memory formation and later retrieval.

Human studies show similar activation of the hippocampal region when associative information is learned. Jackson and Schacter (2004) found hippocampal activation when participants were asked to remember word pairs. An MRI at encoding

showed greater activation in the left anterior hippocampus for word pairs that were remembered versus word pairs that were not remembered in the later recognition test. In other words, there was greater hippocampal activation for successful binding of word pairs than unsuccessful binding of word pairs. Kirwan & Stark (2004) found hippocampal activation for face-name pairs during encoding and retrieval. Similarly in this study, hippocampal activation was greater when the participants remembered the face and name association. Thus greater activation is indicative of successful encoding and retrieval of associative information. Lastly, Eldridge, Engel, Zeineh, Bookheimer, and Knowlton (2005) found that the hippocampus was activated in picture-word associations. In this study, encoding of the associative information was found to activate the anterior portion of the hippocampus, whereas retrieval of this information activated the posterior hippocampus. Therefore, there are a large number of studies in both animal and human literature that support that role of the hippocampus in binding of associative information.

Aging, Binding, and Hippocampal function

As demonstrated, there are numerous studies supporting the role of the hippocampus in binding or associative memory. As well, there are numerous studies reporting structural and biochemical changes in the hippocampus with normative aging. Hippocampal volumes are decreased in older adults, (Driscoll et al., 2003; Kramer et al., 2007) and reduction of hippocampal volume is thought to be due to neuronal loss. Biochemical changes in the hippocampus include a decrease in NAA/Cre values (Driscoll et al., 2003). NAA is a metabolite believed to help develop and maintain white matter, which contains the myelinated axons in the brain. Cre levels are a type of cellular energy that is important in ATP, and this process is important for supplying energy for the brain

to function. Decreases in volume of the hippocampi and NAA/Cre levels correlate with declines in cognitive functioning of memory (Driscoll et al. 2003). Thus these changes imply neuronal death and/or decrease in neuronal density in the hippocampi of healthy older adults. Another study showed the specific areas of the hippocampus affected by these changes. In this study, an MRI designed to assess functionality of hippocampal subregions showed a decline in activation for the subiculum and dentate gyrus with normal aging (Small, Tsai, DeLaPaz, Mayeux, & Stern, 2002).

Johnson and colleagues (Mitchell et al., 2000) have suggested that binding deficits in older adults are due to hippocampal changes. In their study, they examined activation in the hippocampus to see if activation differences in this area were responsible for the associative deficit in older adults. Younger and older adults saw grids with various objects in various locations. After the study phase, participants were asked to respond yes or no to indicate whether the location, object, or both corresponded to grids seen in the study phase. The behavioral results revealed a deficit for older adults' accuracy for combination grids showing location and object. An fMRI scan, which took place during the entirety of the experiment, showed less activation in the hippocampus that could account for binding deficits. For young adults, the left anterior hippocampus showed greater activation for combination trials than for location or object only trials. However, for older adults, there was less activation in this area for combination trials compared to location and object only trials. Therefore, when compared to the object or location task, the combination task, which required featural binding, elicited greater activation in the anterior hippocampus for young adults, but not for older adults. These

results suggest that the lack of activation in this area may be a contributing factor for the age-related binding deficit.

Dennis and colleagues (Dennis et al., 2008) found similar results in their study that required younger and older adults to remember faces, scenes, and face-scene pairs. In the study, fMRI scanning during encoding of the faces, scenes, and face-scene pairs showed there was an age-related binding deficit. Older adults showed less hippocampal activation than young adults. Since hippocampal activation was indicative of successful encoding the results show an age-related deficit in encoding. Specifically, this decline in hippocampal activation was more explicit in face-scene pairs than for faces or scenes individually. Therefore, this study supports the binding deficit in older adults and shows decreased hippocampal activation as a factor in decreased performance. Together these studies suggest that age has an effect on associative memory formation and retrieval and that these processes depend upon the hippocampus.

Error-driven Learning and the Basal Ganglia

It is clear that older adults have difficulty in forming associative memories that depend on intact hippocampal functioning. However, other research shows that older adults do acquire some types of associations. In particular, during predictive or causal learning tasks, older adults acquire simple generative or positive associations between a cue and outcome as readily as younger adults. In one study demonstrating this effect (Parr & Mercier, 1998), participants watched a tank cross a minefield in a video game. The participants were required to learn the causal relationship between the tank being camouflaged or not (cue) and it being safe or not (outcome). This study showed that older

adults were able to acquire the cue-outcome association between tank coloration and safety.

In another study, Mutter and Williams (2004) asked younger and older adults to determine whether pressing or not pressing a spacebar (cue) had any effect on whether a triangle on a computer screen did or did not flash (outcome). The probability that the outcome would occur after the cue varied from -.8 to .8 in .4 increments. Participants were asked to judge how pressing the spacebar influenced the flashing of the triangle. Older adults learned a positive association between pressing the spacebar and triangle flashing as readily as young adults, but they were less able to learn a negative relationship between not pressing the spacebar and triangle flashing. However, the inability of older adults to learn the negative relationship was likely due to their inability to form a representation of the absent cue, which in turn prevented them from forming an association between the cue and outcome. When cues and outcomes are present in the environment, older adults can acquire cue and outcome associations.

Mutter et al. (2009) further demonstrated that older adults have the ability to form cue – outcome associations during a predictive learning task. In this study, Mutter and colleagues used the same causal learning task as in Mutter & Williams (2004), but varied the time between the cue and outcome. This study showed that older adults' causal learning performance was as good as young adults' for generative or positive causal contingencies and that contiguity affected young and older adults' learning in the same way for these generative relationships. Finally, a study by Mutter et al. (2006) showed that older adults are able to form simple cue-outcome associations in a discrimination learning task. In this study, participants had to learn to predict which of two pairs of

symbols on a card was correct. In one case, the presence of a symbol on a pair of cards was correct and, in the other case, the absence of this symbol was correct. The results revealed that older adults were able to learn the rule that would lead to the correct choice for the generative cue-outcome association. Specifically, older adults could articulate the presence of a symbol that made the pair of cards correct in about the same number of trials as young adults. Therefore, there are several studies that provide evidence that age differences are minimal in simple generative cue-outcome associative learning. This, in turn, raises the question of why older adults can learn simple generative associations during predictive or causal learning tasks but have trouble learning simple associations between events in tasks that involve associative binding. One possibility is that while the hippocampus is involved in both associative binding and predictive learning tasks, the basal ganglia are engaged during the error-driven learning processes that occur during predictive and causal learning tasks.

Error driven learning makes actions followed by positive outcomes more likely to occur and those followed by negative outcomes less likely to occur (Holroyd & Coles, 2002). When errors occur, a neural error-related negativity signal is expressed. Specifically, error-related negativity (ERN) or error negativity (Ne) is a negative ERP signal 80 ms after a participants' incorrect response. ERP readings show these negative signals after an incorrect response or error has been made and it is thought that they are associated with correcting the response and keeping the error from occurring again. According to Holroyd and Coles (2002), ERNs increase with learning and should represent the correct response. In other words, learning of the correct answer is indicated by an increase in the ERN signal when the incorrect answer is given.

Studies have shown that error-driven learning requires intact basal ganglia (Shohamy et al. 2004). In one study, Parkinson's disease patients and controls were required to learn which features of a Mr. Potato head figure were associated with the type of ice cream he preferred (Shohamy, et al., 2004). Parkinson's patients were selected based on their specific damage to the basal ganglia. In the feedback–based version of the task, the participants saw a specific Mr. Potato head and then predicted the type of ice cream he would prefer. After their response, they were shown the figure again holding the correct ice cream choice along with "Correct" or "Incorrect" at the bottom of the screen. If they chose correctly, their tip jar on the computer screen increased in monetary value and a sound of coins dropping into the tip jar was played. If they chose incorrectly, the tip jar value did not change and no sound clip was played. This feedback-based version of the task was expected to engage the basal ganglia. In the associative version, the participants saw a Mr. Potato head figure holding his preferred ice cream flavor. They were told to pay attention to the specific aspects (hat, glasses, mustache or bow tie) of the figure and his preferred ice cream flavor (vanilla or chocolate). This associative version of the task was expected to engage primarily the hippocampus. The researchers hypothesized that Parkinson's disease patients would perform better on the associative version of the task than on the feedback-based version of the task due to relatively intact function of the hippocampus, but impaired basal ganglia. The results of the study supported the hypothesis suggesting that error-driven or feedback-based learning reflects learning mediated by the basal ganglia system, which is impaired in Parkinson's patients. Learning of associative tasks seems to be mediated by the basal ganglia in feedback-

16

based or error-driven tasks and by the hippocampus for general associative/observational based tasks.

Aging, Error-driven learning, and the Basal Ganglia

Some research suggests that error-driven learning mediated by the basal ganglia may also be reduced in older adults (Nieuwenhuis et al., 2002). Several studies have found reduced ERN or Ne for older adults compared to young adults (Beste, Willemssen, Saft & Falkenstein, 2009; Nieuwenhuis et al., 2002). In one study, younger and older participants were asked to respond to a letter-version of the flanker task (Niewenhuis et al., 2002). They were presented with a target letter (the middle letter, either H or S) and several distracter letters and were asked to respond with the hand that corresponded to the target letter as quickly as possible. However, the distracters could either be congruent or incongruent with the target letter. While this task was being conducted, ERP measures of ERN amplitude were collected. The results showed reduced ERN amplitudes for older adults compared to young adults. In experiment two of the same study, Nieuwenhuis and colleagues tested the hypothesis that a weakened dopamine system signal is the reason for the age-related reduction in ERN amplitude. Participants were presented with a series of stimuli (buildings, animals, musical instruments, etc.) and were required to respond to each stimulus by pressing one of two buttons. They were then given feedback indicating whether their selection was rewarded or penalized. The responses were set up so that a left button press was rewarded for a certain stimulus and a right button press penalized for the same stimulus or vice versa. The relationship between the stimuli and button press was probabilistic with correct answers being rewarded 100%, 80% or 50% of the time. Performance and ERN measures were collected for the task. Behavioral results showed

younger adults outperforming older adults in the 100 and 80 % conditions, but not the 50 % condition. No difference was observed in the 50 % condition due to the random nature of the pairings. Therefore, no learning was observed for either younger or older adults in this condition. The findings again showed reduced ERNs for older adults as compared to young adults for all the learning conditions. The authors suggested that these results support the hypothesis that aging leads to deficits in the dopamine system. However, as pointed out by Eppinger et al. (2008), not only were older adults' ERNs reduced but their performance levels were also much lower than those of younger adults in Nieuwenhuis' and colleagues study. If ERN levels are based on having a representation of the correct answer, and older adults' performance indicates that they clearly don't have a well-established representation, then they would also have a smaller ERN to the wrong answer. Performance levels should be similar in both groups to reflect an accurate measure of ERN amplitude differences in younger and older adults.

Eppinger and colleagues (Eppinger et al., 2008) compared the ERNs of younger and older adults after equating learning conditions for the two groups by removing the response deadline present in the Niewenhuis et al. (2002) study. Older adults have slower speed of processing; therefore, to show the results are not due to speed deficits the deadline was removed. In their study, participants were presented with colored objects (clothing, vehicles, fruits, vegetables, furniture, and domestic appliances) and asked to respond with one of two button presses. They then received feedback about their accuracy and how much money they had won. The validity of the feedback was also manipulated so that the feedback was valid 100 % of the time, 80 % of the time, or 50 % of the time. Behavioral data showed that in the 100 % and 50 % validity condition there

were no age differences in response accuracy. Age differences were found in the 80 %

validity condition, with older adults' accuracy being worse than young adults'. In

addition, when age differences in learning conditions were equated there were no

differences in the ERNs for young and older adults. These results suggest that the validity

of the feedback is important. Older adults are able to learn cue-outcome associations, but

invalid feedback seems to interfere to a greater extent with their ability to learn these

associations. Therefore, Eppinger's results did not support the idea that there are age-

related deficits in error processing.

Other studies also support the idea that there are no age-related deficits in error

processing. In a study by Friedman et al. (2009), participants made a left or right hand

key press determined by the direction of an arrow on the computer screen. Participants

were randomly assigned to the compatible condition or incompatible conditions, in which

the key press would correspond to the direction or be in opposition the direction of the

arrow, respectively. While the task was being performed, ERP measures were obtained.

The study was not probabilistic in nature and therefore the validity of the trials did not

differ. The results showed similar percent correct for younger and older adults as well as

minimal differences in ERN responses. Therefore, this study supports the notion that

there are no age related differences in ERN response when invalid feedback is eliminated.

Coinciding with this idea, Samanez-Larkin et al., (2007) found no differences in fMRI

activation of the striatum for older and younger adults during an altered monetary

incentive delay (MID) task. During this task, participants saw cues that told them how

much money could be gained or lost in the upcoming test. During the test, participants

were to respond to a target. If they were fast enough in responding to the target, they

19

won or avoided losing the previously determined amount of money. In this study, younger and older adults had similar performance and activation levels in the striatum for gain anticipation. Therefore, these results again suggest that when performance levels are equated, the area responsible for error processing functions normally.

Current Study

In the current study, young and older adults' retrieval performance following associative observation and error – driven learning tasks were compared to determine whether error-driven learning might reduce age-related deficits in associative memory. In both of these tasks, younger and older adults were required to associate physical symptoms with fictional diseases. In the observation version, participants were shown symptom - disease pairs and were instructed to learn these pairs. In the error-driven version, participants first saw a symptom and were asked to predict which disease was associated with the symptom. They then were given feedback on the accuracy of their response. Both versions of the task were self-paced in order to equate learning conditions, as recommended by Eppinger et al. (2008). Associative retrieval following each of these learning tasks was measured by both a prediction and a recall test.

Because both learning tasks were associative in nature, participants were required to bind the disease with the symptom. However, it was expected that the observation learning version would engage primarily the hippocampus, whereas the error-driven version would engage both the hippocampus and the basal ganglia. It was therefore expected that the results for the older adults in the current study would be opposite of the results found for Parkinson's patients in Shohamy et al. (2004). In Shohamy et al. (2004), Parkinson's patients performed better following the observation task than the error-driven

task due to impaired basal ganglia function and relatively intact hippocampal function. However, minimal age differences in the current study were expected following the error-driven task but larger age differences were expected following the observation task due to impaired hippocampal function and relatively intact basal ganglia function.

The design of the study also involved a manipulation of outcome validity. Participants received a valid outcome 100, 75, or 50 % of the time. The effect of age on associative memory performance was expected to vary as a function of learning task and outcome validity. In the 100 % outcome validity condition, it was expected that older adults would perform more poorly than young adults following the observation learning task due to age-related deficits in hippocampal functioning (Driscoll et al., 2003; Small et al., 2002). However, memory performance in the 100% condition was expected to be similar for younger and older adults following the error-driven version of the task due to the contribution of the basal ganglia system (Mutter & Williams, 2004; Mutter et al., 2004; Shohamy & Wagner, 2008). In the 75 % outcome validity condition, older adults were expected to perform more poorly than young adults following both observation and error-driven versions of the learning task due to the probabilistic structure of the task (Eppinger et al., 2008). Finally, in the 50 % outcome validity condition, neither younger nor older adults were expected to learn the cue - outcome associations due to the random relationship between the symptom and outcome. Therefore in this condition, no age differences were expected following either learning task (Eppinger et al., 2008).

CHAPTER 2

Method

Participants

Thirty younger adults (ages 18-29) and 30 older adults (ages 60 and above)

participated in the study. Younger adults were recruited using the Study Board for

Psychology 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, KY and surrounding areas or from a database containing retired faculty

from Western Kentucky University. The older adults were compensated for their time

with a small stipend. Older adults were screened prior to entrance into the study using

the Mini Mental State Exam (MMSE). All participants were required to be fluent in

English and not be taking any medications that could influence cognitive ability. As

shown in table 1, young and older participant samples were representative of the

community and university populations. Neither gender nor ethnicity were of importance

to the study.

Table 1

Participant Characteristics

	Young	Older
N	30	30
Digit Symbol**	78.03(12.55)	65.10(14.05)
Digit Symbol Incidental Learning**	21.73(5.39)	17.00(5.09)
Reading Span*	2.83(.95)	2.23(1.33)
CAL RR**	21.23(9.80)	14.83(9.77)

CAL DF**	2.03(2.36)	3.77(2.59)
CAL P	2.03(2.82)	3.17(3.12)
Mill Hill Vocabulary**	29.27(6.59)	38.07(7.65)
WSCT Categories**	3.57(1.13)	2.70(1.53)

Note. * $p < .05$, **$p < .01$

Experimental Design

The experiment used a 2 (Age) x 2(Learning Task) x 3(Outcome Validity) x 2 (Test) mixed factorial design. Age and learning task were between-subjects factors; and outcome validity and test were within-subjects factors. Fifteen participants were assigned to each Age x Learning Task group. There were three blocks of learning trials in which the participants learned the association between six symptom cues (S1, S2, S3, S4, S5, S6) and two diseases (D1, D2) in each block. The symptoms and diseases were different in each block and the assignment of symptoms to diseases were randomized and counterbalanced across participants. Outcome validity was manipulated by presenting a valid outcome between symptoms and diseases 100, 75, or 50 % of the time after a symptom. For example, in the first block, Symptoms 1, 3, and 5 were paired with Disease 1 100, 75, and 50 % of the time, respectively. Likewise, Symptoms 2, 4, and 6 were paired with Disease 2 100, 75, and 50 % of the time, respectively. Therefore, Symptoms 1 and 2 were always paired with Diseases 1 and 2, respectively. Symptom 3 was paired with Disease 1 75 % of the time and Disease 2 25 percent of the time, whereas Symptom 4 was paired with Disease 2 75 % of the time and Disease 1 25 % of the time. Symptoms 5 and 6 were paired with Diseases 1 and 2 equally often. In each block, there were 96 trials, which were divided into four bins of 24 trials. Within each bin, the correct

symptom and disease pairs were presented 16 times in the 100 % valid condition, 12

times in the 75 % valid condition, and 8 times in the 50 % valid condition. For the 75 and

50 % valid conditions, the remaining four and eight presentations of the symptoms were

with the other disease in the block, respectively. Over the course of the three blocks, there

was a total of 288 trials.

Stimuli and Task

A medical school task scenario was used; participants acted as medical students

learning symptoms that are associated with fictional diseases. Eighteen symptoms from

seven categories (pain, immune, integumentary, respiratory, gastrointestinal, vestibular,

psychological) were selected for use based on non-specific disease association. The

symptoms were: *toothache, pain, fever, pressure, rash, bruising, swelling, hives, pale,*

sweating, cough, nausea, indigestion, diarrhea, dizziness, weakness, depression,

confusion. Six fictional diseases were selected from fictional disease names used in

previous research or were generated by varying the actual names of diseases. These

diseases were: *thatymis, caldosis, renella, hysitoma, scemtosis, visteria.*

Young and older participants were randomly assigned to either the error-driven

version or observation version of the learning task. On each trial of the error-driven

version, participants saw a symptom and predicted which of two diseases was associated

with the symptom by pressing either the G or J key. Following the response, a ding

(Macintosh system sound - glass) denoted a correct answer and a buzz (Macintosh system

sound - basso) denoted an incorrect answer. Then the correct symptom-disease pairing

was presented on the computer screen. On each trial of the observation version of the

task, participants saw a symptom paired with a disease. Participants continued from one

trial to the next by pressing the spacebar key. The symptoms and diseases varied for each block. After the learning task phase, there was a 90 second distracter task in which participants counted backwards from 100 by 3s (as in Naveh-Benjamin, 2000). After the distracter task, participants continued on to the test phase of the experiment. During the test phase, the participants were given both a recall and prediction test for the associated symptoms and diseases. First, in the recall test, each of the 18 symptoms was presented on a sheet of paper and participants were asked to write down the disease that was paired with the symptom. Participants were given each of the six disease names at the top of the page. After completing the recall test, participants completed a prediction test. In the prediction test, participants saw all of the symptoms one at a time and had to choose which one of two disease names went with the symptom. The participants had to choose the correct disease name that was most likely to go with the symptom in both tests. Participants were also told in the prediction test that for every correct answer they would receive 10 cents compensation. After the tests, the participants completed several individual difference measures including: WAIS Digit Symbol and Digit Symbol Incidental Learning (Wechsler, 1997), Conditional Associative Learning (CAL; Levine, Stuss, & Milberg, 1997; Salthouse, 1994) Reading Span (Salthouse & Babcock, 1991), Mill Hill Vocabulary (Wechsler, 1997), and Wisconsin Card Sorting Task (Grant & Berg, 1948; Heaton, Chelune, Talley, Kay, & Curtiss, 1993).

Procedure

Participants completed the study individually in a single session lasting approximately two and a half hours. During this session, they first completed the

informed consent and a biographical questionnaire, which included questions about education, marital status, socioeconomic status, health status, and current medications.

Participants were then seated in front of a computer screen for their experimental task. Instructions appeared that the participants read quietly to themselves. In the error-driven learning task participants read:

For this task, imagine that you are a medical   student who must learn the symptoms that are associated with various diseases. To do this, you will review a series of patient cases. For each case, you will see a symptom on the computer screen. Beneath each symptom, you will see two diseases, one on the left and one on the right. Your task is to predict the disease that is most likely to produce that symptom. When a symptom is presented, you should make your prediction by pressing the key that corresponds to the position of the disease on the screen. To predict the disease on the left, press the G key and to predict the disease on the right, press the J key. Please locate the G and J keys now.

Accuracy is more important than speed in this task, so take as much time as you need to make your prediction. If your prediction is correct, you will hear a pleasant "ding" and if it is incorrect, you will hear an unpleasant "buzz." After this, the symptom will appear with the correct disease. At first you will just be guessing, but eventually you will learn which disease to predict when you see a particular symptom. This is important because later you will be given a test to see how well you have learned the disease that is most likely to produce each symptom.

The first set of patient cases you will see are just for practice to allow you to become familiar with the task. After that you will see patient cases with the symptoms and

diseases you should learn. At times, cases with new symptoms and diseases will be

introduced but the learning task will still be the same.

If you have any questions, please ask the experimenter now. If you are sure you

understand this procedure, you may press the spacebar to begin.

On each trial, the symptom appeared in the middle of the screen and the prompt: "Disease?" appeared below the symptom. Participants made their selection by pressing the key corresponding to the selected disease. A ding indicated a correct answer; a buzz indicated an incorrect answer. Then the screen showed the correct symptom disease pair. The timing of stimulus events was as follows: a fixation point appeared for 500 ms. Then the stimulus appeared for 500 ms followed by the disease prompt until the response. Two thousand milliseconds after the response, the feedback tone sounded. The symptom then appeared above the correct disease in the center of the screen and was displayed for a minimum of 3 seconds or until the participant responded. The spacebar allowed the participant to proceed to the next trial, as indicated on the screen.

In the observation learning task, participants were given the following instructions:

For this task, imagine that you are a medical student who must learn the

symptoms that are associated with various diseases. To do this, you will review a series

of patient cases. For each case, you will see a symptom paired with a disease on the

computer screen. You should pay close attention to each symptom-disease pair and try to

remember it. This is important because later you will be given a test to see how well you

have learned the disease that is most likely to produce each symptom.

The first set of patient cases you will see are just for practice to allow you to become familiar with the task. After that you will see patient cases with the symptoms and diseases you should learn. At times, cases with new symptoms and diseases will be introduced, but the learning task will still be the same.

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

As in the error-driven learning task the stimulus events began with a 500 ms fixation point. Then the symptom-disease pairs stayed on the screen until the participant responded. After both versions of the learning task, participants completed a 90 second distracter task and then proceeded to the test phase. In the test phase, all participants received a recall test followed by a prediction test.

After the experimental task, the participants were asked to complete Wisconsin Card Sorting Task (WCST), Digit Symbol, Digit Symbol Incidental Learning, Reading Span, Mill Hill Vocabulary, and Conditional Associative Learning (CAL). After the completion of the tasks, the participants were debriefed, thanked, and compensated for their time.

CHAPTER 3

Results

The prediction accuracy data for the error-driven learning task were analyzed using an ANOVA with the between-subjects factor Age Group (Younger, Older), and within-subjects factors Validity (100%, 75%, 50%) and Bin (Bin1, Bin2, Bin3, Bin4). Mean accuracy for each bin in each validity condition is reported in Figures 1, 2, and 3. The analyses conducted used an alpha level of $p \leq .05$ as the criterion of significance. There was no main effect of age, $F(1, 28) = 1.8$, $MSE = .07$, $p = .19$. In addition, Age X Bin, $F(3, 84) = .94$, $MSE = .01$, $p = .43$, Age X Validity, $F(2, 56) = .65$, $MSE = .03$, $p = .53$, and Age X Bin X Validity, $F(6, 168) = 1.67$, $MSE = .01$, $p = .13$, interactions were not significant. Therefore, learning across bin and validity was similar for younger and older adults.

The analysis revealed a significant effect of bin, $F(3, 84) = 15.19$, $MSE = .01$, $p < .0001$, $\eta^2 = .352$, showing that prediction accuracy differed across the bins. There was also a significant effect of validity, $F(2, 56) = 74.37$, $MSE = .03$ $p < .0001$, $\eta^2 = .73$, indicating that there was a change in prediction accuracy across validity conditions. These significant main effects were qualified by a significant Bin X Validity interaction, $F(2, 168) = 2.47$, $MSE = .01$, $p < .05$, $\eta^2 = .081$. A test of the simple effect of bin within each validity condition showed significant effects of bin for the 100, $F(3, 84) = 13.17$, $MSE = .01$, $p < .0001$, $\eta^2 = .32$, and 75 % validity conditions, $F(3, 84) = 6.16$, $MSE = .02$, $p < .0001$, $\eta^2 = .18$, but not for the 50 % condition, $F(3, 84) = 2.43$, $MSE = .01$, $p < .07$, $\eta^2 = .08$. Simple contrasts of bin for the 100% and 75% validity conditions showed that the majority of learning occurred in the first bin for both conditions [100 % Validity:

Bin 1 vs. Bin 2, F (1, 29) = 16.44, MSE = .02, p < .0001; Bin 2 vs. Bin 3, F (1, 29) = .987, MSE = .02, p = .33, Bin 3 vs. Bin 4, F (1, 29) = .407, MSE = .01, p = .41; 75% Validity: Bin 1 vs. Bin 2, F (1, 29) = 4.83, MSE = .04, p = .04, Bin 2 vs. Bin 3, F (1, 29) = 2.62, MSE = .02, p = .12, Bin 3 vs. Bin 4, F (1, 29) = .01, MSE = .02, p = .91].

These analyses of the learning task data revealed similar prediction accuracy scores for younger and older adults during the error-driven learning task. The majority of learning was also found to have occurred in the first bin for 100 % and 75 % conditions. No learning occurred in the 50 % condition.
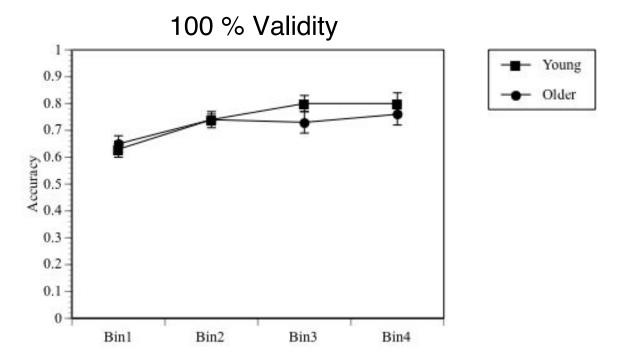
Figure 1. Younger and older adults' mean accuracy across bin for the 100 %
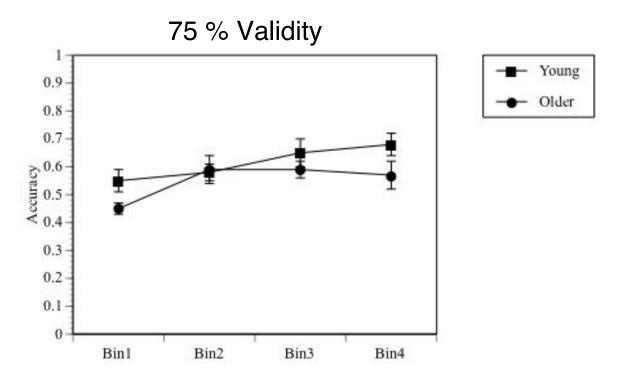
validity condition.

75 % Validity

Figure 2. Younger and older adults' mean accuracy across bin for 75 % validity.
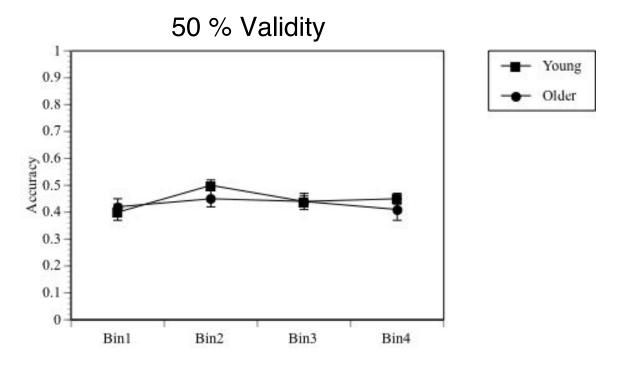
50 % Validity

Figure 3. Younger and older adults' mean accuracy across bin for 50 % validity.

Prediction and Recall Test Retrieval Accuracy

Accuracy data for the prediction and recall tests were analyzed using an ANOVA with between-subjects factors Age Group (Younger, Older) and Learning Task (Error-driven Task, Observation Task), and within-subjects factors Outcome Validity (100%, 75%, 50%) and Test (Prediction Test, Recall Test).

Tables 2 and 3 show the ANOVA results and the mean accuracy scores for the prediction and recall tests, respectively. As shown in Table 2, there was a significant main effect of age; older adults' overall accuracy was lower than younger adults. There was no main effect of learning task; however, an Age X Learning Task interaction was revealed. An analysis of the simple effects of age for each learning task showed a main effect of age for the error-driven learning task, $F (1, 28) = 12.51$, $MSE = .01$, $p < .001$, $\eta^2 = .31$, but not for the observation learning task, $F (1, 28) = .06$, $MSE = .01$, $p = .81$, $\eta^2 = .94$. Therefore, older adults' overall test performance was worse than younger adults'

performance following the error-driven learning task condition, but not following the

observation learning task.

Table 2

ANOVA for Prediction and Recall Test Data

Between subjects					
Effect	*df*	*MS*	*F*	η	*p*
Age*	1	.54	6.68	.11	.012
Learning Task	1	.02	.30	.005	.589
Age X Learning Task*	1	.41	5.01	.08	.029
Error	56	.08			
Within subjects					
Validity**	2	1.45	30.48	.35	.000
Age X Validity**	2	.24	5.15	.08	.007
Learning Task X Validity	2	.02	.36	.01	.697
Age X Learning Task X Validity	2	.00	.03	.00	.969
Error	112	.05			
Test**	1	3.90	181.43	.76	.000
Age X Test**	1	.21	9.74	.15	.003
Learning Task X Test	1	.00	.02	.00	.888
Age X Learning Task X Test	1	.01	.46	.01	.499

	df	MS	F		p
Error	56	.02			
Validity X Test	2	.00	.23	.00	.793
Age X Validity X Test *	2	.05	2.93	.05	.058
Learning Task X Validity X Test	2	.03	1.71	.03	.185
Age X Learning Task X Validity X Test	2	.01	.45	.01	.641
Error	112	.02			

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

Table 3

Younger and Older Adults' Mean Accuracy (SD) for Prediction and Recall Tests in Validity and Learning Task Conditions

	Prediction Test		Recall Test	
	Younger	Older	Younger	Older
Observation Learning Task				
100%	.72 (.15)	.68 (.15)	.51 (.22)	.42 (.22)
75%	.58 (.21)	.59 (.20)	.41 (.26)	.29 (.16)
50%	.41 (.18)	.52 (.19)	.27 (.18)	.33 (.22)
Error-driven Learning Task				
100%	.81 (.13)	.62 (.20)	.62 (.26)	.39 (.26)
75%	.62 (.15)	.56 (.14)	.57 (.26)	.26 (.15)
50%	.49 (.15)	.48 (.19)	.29 (.22)	.22 (.15)

The analysis also revealed a main effect of validity, an interaction between age and validity, and non-significant Learning Task X Validity and Age X Learning Task X Validity interactions. A significant main effect of test was also found and there was also a significant Age X Test interaction. However, Learning Task X Test, Validity X Test, Age X Learning Task X Test, Learning Task X Validity X Test, and Age X Learning Task X Validity X Test interactions were not significant.

The age, validity, and test main effects along with the Age X Test and Age X Validity two-way interactions were qualified by an Age X Validity X Test three-way interaction. Although this interaction effect was marginally significant, separate Age X Test simple interaction analyses for the 100%, 75%, and 50% validity conditions were conducted based on the relevance of the outcome of these analyses to the a priori hypotheses of this study. Figures 4 and 5 show young and older adults' mean percent correct in each test for the three validity conditions collapsed over learning task. For 100 % validity, the analysis revealed a main effect age, $F(1, 58) = 8.93$, $MSE = .06$, $p > .01$, $\eta^2 = .13$ and test, $F(1, 58) = 76.94$, $MSE = .02$, $p > .0001$, $\eta^2 = .57$. The age by test interaction was not significant, $F(1, 58) = .79$, $p = .38$, $\eta^2 = .01$. Therefore, in the 100% validity condition, older adults performed more poorly than younger adults and both age groups performed better on the prediction test than the recall test. For the 75% validity condition, there were main effects of age, $F(1, 58) = 7.23$, $MSE = .06$, $p < .01$, $\eta^2 = .11$, and test, $F(1, 58) = 57.33$, $MSE = .02$, $p < .0001$, $\eta^2 = .56$, but there was also an age by test interaction, $F(1, 58) = 15.67$, $p < .0001$, $\eta^2 = .21$. Further analyses were conducted in order to examine age differences separately for prediction and recall tests within this

validity condition. For the prediction test, there was no age difference in performance, F (1, 58) = .283, p = .60, η^2 = .00; however, for the recall test, there was a significant effect of age, F (1, 58) = 14.88, $p < .0001$, η^2 = .20. Therefore older adults' accuracy was lower than younger adults' in the 75 % condition of the recall test, but was similar in the 75 % condition of the prediction test. In the 50 % condition, there was a non-significant effect age, F (1, 58) = .38, MSE = .05, p = .54, η^2 = .01, a significant main effect of test, F (1, 58) = 57.33, MSE = .02, $p < .0001$, η^2 = .50, and a non-significant age by test interaction, F (1, 58) = 1.02, p = .32, η^2 = .02. Therefore, there was no age difference in this condition. Across the two groups, retrieval performance was low for both the prediction test (M = .47, SD = .18) and the recall test (M = .28, SD = .19).

The analyses of the prediction and recall retrieval data revealed an age difference associated with learning task. Older adults' overall retrieval performance was worse than younger adults following the prediction learning task, but not the observation learning task. There was also an age difference associated with the combination of validity and test type. In the 100 % validity condition, older adults' accuracy was consistently worse than young adults' and the recall test yielded lower accuracy than the prediction test. In the 75 % condition, age differences depended on the test type. Older adults' performed worse than younger adults' for the recall test and similarly for the prediction test. In the 50 % condition, the recall test performance was lower than prediction test performance, but performance was similar for the two age groups.
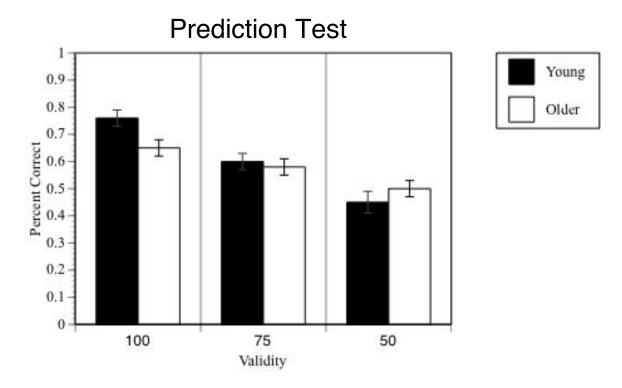
Prediction Test

Figure 4. Younger and older adults' mean percent correct across validity
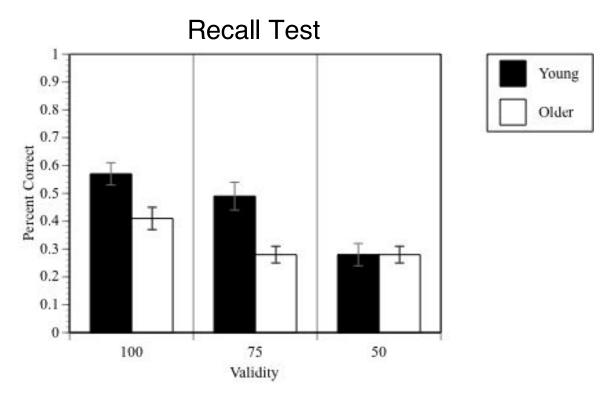
conditions for prediction test.

Recall Test

Figure 5. Younger and older adults' mean percent correct across validity conditions for observation test.

Younger and Older Adults' Individual Differences Correlations

As shown in Table 4, correlational analyses were performed to determine whether prediction and observation retrieval accuracy were related to perceptual speed (Digit Symbol), working memory (Reading Span), executive function (WSCT), learning and memory (CAL), and crystallized verbal intelligence (Mill Hill). Older adults' CAL retained responses were positively correlated with 100 % valid prediction test scores. Younger adults' Mill Hill Vocabulary scores were positively correlated with 75 % valid prediction test scores. None of the other correlations between test scores and individual difference measures were significant. However, as shown in the table, several correlations were marginal which could be due to low power.

Table 4

Correlations for Individual Difference Measures with 100 % and 75% Validity Conditions

for Recall and Prediction Test measures

	100 % Validity				75 % Validity			
	Recall	*p*	Predict	*p*	Recall	*p*	Predict	*p*
Younger								
Digit Symbol	.26	.16	.06	.73	.31	.09	.06	.77
DS Incidental	.29	.12	.27	.15	.35	.06	.24	.21
Reading Span	.10	.60	.20	.29	-.03	.87	.13	.51
CAL RR	.08	.69	.21	.26	.26	.16	.19	.33
CAL DF	.15	.44	-.03	.89	-.11	.56	-.08	.66
CAL P	-.15	.41	-.24	.20	-.34	.06	-.17	.36
Mill Hill Vocab.	.12	.52	.22	.23	.19	.30	.49 **	.01
WCST Categories	.25	.17	.02	.92	.17	.36	.09	.62
Older								
Digit Symbol	.15	.43	-.02	.92	.03	.87	.31	.09
DS	.11	.58	.33	.07	.17	.35	.21	.27

Incidental Reading Span	.05	.77	.21	.25	.21	.26	.23	.21
CAL RR	.22	.23	.38*	.04	.16	.41	.18	.34
CAL DF	-.12	.52	-.30	.10	-.12	.52	-.11	.57
CAL P	-.24	.19	-.28	.13	-.08	.65	-.25	.19
Mill Hill Vocab.	-.02	.91	.03	.88	.32	.08	.26	.17
WCST Categories	-.32	.08	-.21	.26	.23	.21	.22	.23

Note. *$p \leq .05$. ** $p \leq .01$.

CHAPTER 4

Discussion

The current study aimed to examine age-related differences in error-driven and associative learning. The results showed that there were no age differences in prediction accuracy during an error-driven learning task. The results also revealed that the majority of learning occurred within the first bin for 100 and 75 % outcome validity conditions; no learning occurred in the 50 % validity condition due to the random feedback. In contrast to the learning task results, subsequent prediction and recall test results revealed that older adults' overall performance across the two types of tests was worse than younger adults' following the error-driven learning task. However, younger and older adults' performance was similar following the observation learning task. Thus, age differences in associative memory performance varied as a function of learning task, but not in the hypothesized direction. Age differences also did not vary as a function of the combination of learning task and validity as expected. However, age differences in memory did vary as a function of the combination of validity and test type, which was not predicted. In the 100 % outcome validity condition, older adults' overall performance across the two types of associative memory tests was worse than younger adults' and performance for both groups was lower for the recall test than the prediction test. For the 75 % condition, older adults performed more poorly on the recall test than younger adults, but their performance was similar on the prediction test. In the 50 % condition, prediction test performance was better than recall test performance due to different chance probabilities, but overall retrieval performance was poor because there was no valid outcome. Age did not play a role in this condition.

Associative Learning and Memory Performance - Comparison to Hypothesized Results

Although no predictions were made regarding age differences in performance during the error-driven learning task, the findings are important. Younger and older adults' learning performance was similar for this learning task, which suggests that error-based learning processes are intact for older adults. No comparable data was obtained for the observation learning task based on absence of recorded responding from participants in this condition. The results of this study are therefore consistent with previous literature showing that older adults and younger adults have similar rates of overall learning in an error-driven task (Eppinger et al., 2008; Pietschmann, Endrass, Czerwon, & Kathmann, 2011). Learning was also found to mostly occur during the first bin for 100 and 75 % outcome validities, but not for the 50 % condition in which no learning occurred. These results again are consistent with the learning curves found in previous research (Eppinger et al., 2008).

Although there were no age differences on the error-driven learning task, this did not translate to a corresponding absence of age differences in later associative memory performance. The effect of age on associative memory performance was expected to vary as a function of learning task and outcome validity. In the 50 % outcome validity condition, younger and older adults' performance was expected to be similar for both learning tasks, due to the random feedback given in this condition. However, prediction test performance was expected to be better than recall test performance since the prediction was a two choice task and recall, a six choice task. This expected result was observed in the current study. In the 100 % outcome validity condition, older adults were

43

expected to perform worse than younger adults following the observation learning task due to age-related deficits in hippocampal functioning. Older adults, however, were expected to perform like younger adults following the error-driven learning task due to basal ganglia contribution. In the 75 % validity condition, older adults were expected to perform more poorly than young adults for both observation and error-driven versions of the learning task due to the probabilistic structure of the task. The results revealed that, except for the 50 % validity condition, older adults' overall memory performance was worse than younger adults following the error-driven learning task, but performance was similar for the two age groups following the observation learning task. Therefore, the expected effects of learning task and outcome validity on associative memory were not supported.

Older adults' worse memory performance than younger adults' following the error-driven task suggests that although no age differences were present during the error-driven learning task, this task was not as effective for older as for younger adults. Eppinger et al. (2008) did not include later retrieval tests. Therefore, our results must be compared to previous research with error-driven and observation learning tasks followed by retrieval tests. This prior research has shown age differences in younger and older adults' prediction test performance following feedback based or error-driven learning, but similar performance following observation learning (Schmitt-Eliassen et al., 2007), which is replicated in the results of the current study.

The findings in the current study also did not support the prediction that older adults' performance would be opposite of the results found for Parkinson's patients (Shohamy et al., 2004). In their study, Parkinson's patients performed better following

the observation task than the error-driven task due to impaired basal ganglia function and relatively intact hippocampal function (Shohamy et al., 2004). Replicating Shohamy et al.'s results (2004), Schmitt-Eliassen and colleagues (Schmitt-Eliassen et al., 2007) conducted a study that showed test performance was better for older adults and Parkinson's disease patients in the observation condition versus the error-driven or feedback condition. However, in their study, no additional prediction test deficit was shown for Parkinson's patients versus healthy older adults, which they interpreted to mean that loss of dopamine did not play a role in the feedback condition. Additionally, in the last test block of the feedback condition, Schmitt-Eliassen et al. (2007) found chance level performance for Parkinson's disease patients and older adults. In contrast, the learning blocks of the feedback condition showed similar learning for younger adults, older adults and Parkinson's disease patients. Therefore, similar to our study, Schmitt-Eliassen and colleagues' (2007) study showed age differences during a prediction test, but not during prediction learning. Future research should be conducted to distinguish the differences between error-driven learning processes and subsequent retrieval processes following this type of learning.

Unlike Eppinger et al. (2008), our study also was comprised of two different tests to assess remembered information. Although older adults' error-driven learning performance was similar to that of younger adults, there were age differences in associative memory performance that varied as a function of outcome validity and test type, which was not expected. In the two non-random outcome conditions, younger adults outperformed older adults for all but the 75 % outcome validity condition for the prediction test showing that they had a substantial deficit in associative memory. Young

adults were clearly better at retrieving the symptom disease pairs than older adults. This finding is consistent with previous literature showing age differences in associative memory (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000).

Previous research suggests that older adults are more affected by probabilistic structure than younger adults in certain conditions (Eppinger et al., 2008). For example, Eppinger and colleagues (Eppinger et al., 2008), found age differences in accuracy in the 80 % outcome validity condition of an error-driven learning task. However, the lack of age differences within the 75 % outcome validity condition of the learning portion of our study is not consistent with this finding. Retrieval test findings for our study also disputes the idea that older adults are more affected than younger adults by probabilistic structures. The presence of age differences for the 100 % outcome validity condition combined with the lack of age differences for the 75% validity condition on the prediction test actually suggests that younger adults' performance was more affected by outcome uncertainty than older adults'. The disruption of younger adults' performance in the 75 % outcome validity condition suggests that they learned both low probability and high probability outcomes and may have sometimes deliberately picked the lower probability symptom. As a result, their prediction performance in this condition was disrupted relative to the 100 % condition where there was no low probability answer. Older adults, in contrast, picked the alternate low probability or incorrect choice fairly often for both the 75 % and 100 % conditions suggesting a general associative memory failure for both outcome validity conditions. Therefore, the age difference in the 75 % outcome validity prediction test data is more likely a reflection of disruption of younger adults' performance than older adults' benefit from the prediction test.

As with any research, this study was not exempt from limitations. One such limitation was the small sample size. The age difference that varied by validity and test type was of marginal significance, ($p = .058$). Perhaps with more participants, this effect would be significant. Another limitation involves the inability to measure hippocampal and basal ganglia brain activation by fMRI and ERP measures while conducting this study. Although our findings were consistent with previous studies of associative learning in which brain activation was measured, the results would be more complete if we could have our own measurements for this study. Similar basal ganglia ERP imagery data and differences in fMRI hippocampal activation for younger and older adults would further support behavioral data showing normal error-driven learning processes and abnormal associative memory for older adults.

In conclusion, although the results of our study support normal error-driven learning processes for older adults, they do not support the idea that error-driven learning enhances older adults' associative memory. Our study confirms prior findings showing that age differences in associative memory are greater following an error-driven learning task than following an observation learning task (Schmitt-Eliassen et al., 2007; Shohamy et al., 2004). Therefore, the results of the study did not support enhanced associative memory for older adults due to error-driven processing. Further research should be conducted to help clarify the role of the basal ganglia as well as the role of learning task and test type on associative memory performance.

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