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The Effects of Aging on Attention in Associative Learning

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THE EFFECTS OF AGING ON ATTENTION IN ASSOCIATIVE LEARNING

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In this study we investigated how aging affects attention to predictive and uncertain cues during associative learning. According to Mackintosh's theory of predictiveness (1975), attention will be allocated to cues that most reliably predict an outcome. An opposing theory of uncertainty from Pearce and Hall (1980) suggest attention will be allocated to cues whose outcomes are uncertain. Although these theories are contradictory, both are well supported in the associative learning literature. There is evidence that young and older adults give more attention to cues that are predictive compared to nonpredictive cues (Mutter et al., 2019), and that young adults respond faster to cues with certain outcomes compared to cues with uncertain outcomes (Luque et al., 2017). However, previous research has not examined the effects of these two types of attention in the same experiment with older adults. In this study, . a category learning task that assessed the accuracy of outcome responses alternated with a dot probe task that assessed attention to cues. Young and older adult participants were presented with pairs of cues and had to learn which one of two categories each pair of cues was associated with. The predictive cue within a compound provided reliable information about what category that particular compound belonged to, whereas the nonpredictive cue did not provide any useful information about category membership. In the last stage of learning, one compound cue maintained its relationship with the outcome it was previously associated with, while the other compound cue was associated with the previously learned outcome two-thirds of the time and was associated with the other category the remaining one-third of the time. We found that both young and older adults

responded faster to a predictive cue compared to a nonpredictive cue. In addition, both young and older adults were slower in responding to an uncertain cue pair compared to a certain cue pair. These results replicated previous findings (Luque et al., 2017; Mutter et al., 2019) and extended them to older adults. The novel findings of no age differences in attention to predictive and uncertain cues suggest that older adults do not experience an attentional deficit in associative learning. Future research including tests of associability will provide more information on how cue predictiveness and uncertainty effects subsequent learning in older adults.

CHAPTER 1

Introduction

Considerable research has shown that attention and learning interact in complex ways (Mitchell & Le Pelley, 2010). Attention refers to how people actively process information in their environment. It is the gateway between the plethora of information that is available to us and the much smaller set of information we actually use. Predictiveness and uncertainty are two factors that influence attention in associative learning. Mackintosh (1975) proposed a theory of predictiveness that claims attention will be given to the cue that is most predictive of an outcome. In contrast, Pearce and Hall (1980) claim that attention will be given to the cue whose outcome is uncertain in order to learn about its predictive value.

Most of the research supporting these two theories have focused on young adults, and there is little research on attentional processes during associative learning for older adults. There is evidence that young adults are more efficient at acquiring cue-outcome relationships compared to older adults (Mutter, Atchley, & Plumlee, 2012; Mutter, DeCaro, & Plumlee, 2009). However, it unknown whether there is an age–related deficit in the attentional processes that interact with associative learning. Preliminary findings from a recent study suggest there is no decline in older adults' ability to attend to predictive stimuli (Mutter, Holder, Mashburn, & Luna, 2019). But what happens when the outcome is uncertain? There are currently no studies on how uncertainty affects attention in older adults during associative learning. Therefore, the current study seeks to replicate previous findings that older adults attend to predictive stimuli similarly as young adults do. In addition, this study will examine the effects of uncertainty on young and older adults' attention in associative learning.

Theories of Attention in Associative Learning

Rescorla-Wagner Model

The Rescorla-Wagner model (1972) is one of the most well-known theories of associative learning. In this theory, Rescorla and Wagner (1972) suggest that learning occurs as a result of surprise. More specifically, learning only occurs when an event violates an expectation. For example, let's say a rat will receive a foot shock when a tone is presented. During initial learning trials, the tone does not predict a foot shock, so the rat is surprised at the occurrence of the shock, and learning for the tone – shock association occurs. After learning occurs, the rat isn't surprised that the tone predicts the shock and no further learning occurs. However, if the tone then occurs and the rat does not receive the shock, the rat is now surprised and learning again occurs. Also, if the tone occurs and a stronger shock occurs, the rat is surprised, and learning should occur.

The Rescorla-Wagner idea of surprise was anticipated by the classic blocking experiment by Leon Kamin (1969). In Phase 1 of this experiment, the first group of rats received 16 trials in which a noise was paired with a shock, and the second group received trials in which a compound stimulus of a light and noise was paired with a shock. In Phase 2, the pairings were switched. Therefore, Group 1 received the light-noise compound paired with a shock and Group 2 received only the noise paired with a shock. In Phase 3, the rats were tested by only presenting the light paired with a shock. The results showed that Group 1 showed no evidence of learning at all for the light cue, but Group 2 showed conditioning to the light. Based on these results, it appeared that the rats in Group 1 who had prior conditioning with the noise “blocked” conditioning of the light. Kamin proposed the reason for this was because the rats in Group 1 learned that the noise would predict the shock and were not surprised when this outcome occurred. However, the rats in Group 2 learned the compound stimulus first, so significant conditioning to the light occurred. This experiment suggests that learning will only occur if the outcome is surprising. In addition, Kamin suggested that the rats in Group 1 must have selectively allocated attention to the noise, but not to the light in Phase 2.

Although learned attention was not represented in the original Rescorla-Wagner model, there was an alpha parameter that represented the physical salience of the cue. Salience refers to the ability of a stimulus to capture attention (Le Pelley, Mitchell, Beesley, George & Wills, 2016). For example, a bright flashing light such as blue police lights are more salient than a dull light such as a headlight on a car because the bright flashing light is going to capture your attention better. Salience influences the potential associability of a cue, which is the ease with which stimuli can be learned about. Specifically, the amount of surprise at the occurrence of the outcome is multiplied by cue salience, so salience influences the rate of learning for a particular cue. However, as Kamin (1969) suggested, the salience of a cue can be affected by learning. Mackintosh and Turner (1971) conducted an experiment to determine if blocking is due to a limitation on attention to the blocked cue. In Phase 1, both the experimental and control group received initial conditioning with a noise (cue) and a shock (outcome) until the rats had completely learned about the cue-outcome relationship. In Phase 2, only the experimental group received several trials in which a light-noise compound stimulus was paired with the shock. In Phase 3, both groups were presented with a light-noise compound cue that was paired with an even larger shock. Finally, both groups were tested by presenting only the light to see if learning occurred. Their results suggest that exposure to the LN-shock trials in Phase 2 reduced the associability of the light in Phase 3 even though the outcome was larger. Mackintosh and Turner (1971) suggested the animals recognized the light as a redundant predictor of a shock in Phase 2, and because of that the rats gave less attention to it. Consequently, there was no learning about the light in Phase 3 because the rats had learned to ignore it.

Revisions to the Rescorla-Wagner Model

To address the evidence that learning could affect the salience of cues, two revisions to the Rescorla-Wagner model were proposed: Mackintosh's (1975) theory of predictiveness and the Pearce and Hall (1980) theory of uncertainty.

Mackintosh's Theory of Predictiveness. Mackintosh (1975) proposed an extension of the RW theory that claimed attention will be allocated to cues that most reliably predict an outcome, and attention will decrease to cues that are unreliable predictors of an outcome. Mackintosh claimed that as cues become more predictive (less predictive), the R-W alpha parameter (salience parameter) increases (decreases) and associability increases (decreases). Intuitively, this appears to be a credible account of how learning and attention interact; i.e., humans and animals will learn more readily about predictive cues because they have greater associability. For animals, this might be a cue that predicts the arrival of food (such as a smell) or pain (such as an electric shock). Therefore, Mackintosh views attention as a filter that removes the excess noise and enables us to respond to the most predictive source of information (Le Pelley et al., 2016).

Along with the Mackintosh and Turner (1971) findings, there is substantial behavioral evidence for Mackintosh's theory of predictiveness in the literature on associative learning. For example, Le Pelley and McLaren (2003) asked participants to predict what kind of allergic reaction (e.g. sweating, dizziness, nausea, or itching) would occur when a fictitious patient ate particular foods. There were two training phases where participants were able to learn about the relationship between types of food (cue) and types of allergic reaction (outcome) by receiving immediate feedback throughout the trials. In Phase 1, "Mr. X" was a patient who experienced either dizziness or sweating as a result of eating foods to which he was allergic. Throughout the training, participants learned that certain cues (e.g., apples) would reliably predict which type of allergic reaction the patient would experience. There were also non-predictive cues (e.g., bananas) that were paired half of the time with dizziness and half of the time sweating. So, each pair of food that was presented included a predictive cue and a nonpredictive cue. In Phase 2 "Mr. Y" was a new patient who ate the same foods as Mr. X but experienced different types of allergic reactions. For example, participants might see that Mr. Y ate apples and bananas and experienced nausea instead of dizziness as the outcome. So, Phase 2 consisted of a pair of foods with one cue that was predictive for Mr. X in Phase 1 and one cue that was non-predictive with new outcomes. After Phase 2, participants were given a final test of cue-outcome pairs in which a pair of food was presented; then participants had to indicate what type of allergic reaction would occur. The results showed that participants learned new outcomes for cues that were previously predictive better than cues that were previously non-predictive. This finding demonstrates how learned predictiveness led to greater associability because cues that were predictive in Phase 1 were learned more readily compared to the nonpredictive cues. There have been many other studies suggesting that predictiveness is associated with increased associability in animals (Bennett, Wills, Oakeshott & Mackintosh, 2000; Oswald et al., 2001; Mackintosh & Little, 1969) and humans (Beesley and Le Pelley, 2010; Bonardi, Graham, Hall & Mitchell, 2005; Kruschke, 1996) and that cues with greater associability are learned about more readily (Mitchell, Harris, Westbrook & Griffiths, 2008; Brandon, Vogel & Wagner, 2003; Le Pelley, 2004; Kruschke, 2006).

Pearce-Hall Theory of Uncertainty. Pearce and Hall (1980) proposed a theory that was quite different from Mackintosh's (1975) theory of predictiveness. Ironically, the Pearce-Hall (1980) theory of uncertainty was developed from the results of an experiment that was intended to support Mackintosh's theory (1975). Hall and Pearce (1979) were interested in investigating the degree to which the association of a cue-outcome relationship could be modified by cue-outcome pairings. In Phase 1, two groups of rats were conditioned in which the first group received initial conditioning trials with a tone and a weak shock, and the second group received conditioning with a light and a weak shock. In Phase 2, both groups received conditioning trials with the same tone used in Phase 1 and a stronger shock. Following Mackintosh's (1975) theory of predictiveness, they expected that Group 1 would learn especially quickly because during Phase 1, the tone was established as a good predictor of the outcome. Therefore, the rats should have been paying attention to the tone at the beginning of Phase 2 and learn about it rapidly. However, instead of demonstrating rapid learning, the opposite occurred. Hall and Pearce found that Group 1 was slower than Group 2 to learn about the tone in Phase 2 even though the shock had previously been a good predictor of the outcome. Therefore, it appears that the prior training of Group 1 with the tone and a weak shock reduced the associability of the tone and a stronger shock in Phase 2. Because the stronger shock in Phase 2 was surprising for Group 1, more attention was given to it to learn about its predictive value. Given these unexpected findings, this led Pearce and Hall to develop a new theory of attention in associative learning that focused on the opposite of cue predictiveness.

Pearce and Hall's (1980) model suggested that attention will be directed towards stimuli whose outcomes are uncertain. The prediction error is an important aspect of the Pearce and Hall (1980) theory of uncertainty. For example, if an outcome is different than what was predicted, either the absence of a predicted outcome or the occurrence of an unpredicted outcome, a prediction error occurs. According to Pearce and Hall (1980), prediction error changes the alpha parameter. Contrary to Mackintosh (1975), the Pearce-Hall theory suggests that the salience of good predictors of an outcome should decrease over the course of learning, and the salience of uncertain predictors of an outcome should increase in order to facilitate learning. Their rationale for this change in the alpha parameter is that if a stimulus is a reliable predictor of an outcome, there is no possibility for further learning. But if the outcome of a stimulus is uncertain, there is an opportunity to learn more about its predictive value. However, it should be noted that Mackintosh's theory refers to the subsequent associability of the most predictive cue with an outcome, whereas Pearce and Hall refer to the associability of the cue within the context of what is happening in the current trial.

As with the Mackintosh theory, there is also significant behavioral evidence to support the Pearce-Hall (1980) theory (Haselgrove, Esber, Pearce & Jones, 2010; Swan

& Pearce, 1988; Hogarth, Dickinson, Austin, Brown & Duka, 2008). For example, Griffiths, Johnson, and Mitchell (2011) used negative transfer to provide unique support for the Pearce-Hall theory. In this study, participants imagined they were allergists and had to learn about the strength of allergic reactions when Mrs. X ate certain foods. The degree of allergic reaction was either rated as none, minor, severe, or critical. On each trial, following the presentation of a cue, participants had to judge the severity of the allergic reaction (none, minor, severe, or critical) and also rate the confidence of their judgements on a 6-point Likert scale ranging from 1-Not at all confident to 6-Very confident. During Phase 1, participants in both the Negative Transfer group and participants in the Change group learned the target cue was paired with a minor allergic reaction. In Phase 1a, participants in the Change group learned that now the target cue was paired with no allergic reaction and nothing changed in the Negative Transfer group. In Phase 2, uncertainty was introduced by presenting both groups with a severe allergic reaction (Griffiths et al., 2011). The findings showed that participants significantly increased their ratings to the cues upon the surprising outcome because they learned about the new cue-outcome relationships of a severe allergic reaction in Phase 2. Consistent with the Pearce-Hall theory, the results demonstrated that the surprising new outcomes in Phase 2 increased uncertainty about the new cue-outcome relationships, which led to rapid learning.

Hybrid Models of Attention in Associative Learning. The studies reviewed so far provide evidence in support of both the Mackintosh (1975) and Pearce and Hall (1980) models of attention in associative learning. However, the evidence that supports one theory contradicts the other. So, what does this mixed evidence mean? Because both theories are equally supported, some theorists have attempted to develop a unified model combining ideas from both Mackintosh (1975) and Pearce and Hall (1980). Recently, Pearce and Mackintosh (2010) suggested that one important difference between their two theories is that they are ultimately describing different aspects of learned attention to cues. They claim Mackintosh's (1975) theory of predictiveness describes the mechanism that controls attention to stimuli that have already been learned. In contrast, the Pearce-Hall (1980) theory of uncertainty describes the attentional processing that is necessary for learning about a cue. Moreover, the Mackintosh (1975) theory focuses on the predictive values of cues within the array of all cues in an environment, whereas the Pearce-Hall (1980) theory focuses on how certain or uncertain an animal/person may be about the outcome of a specific cue, which is driven by the degree of prediction error for that cue.

Pearce and Mackintosh (2010) have also linked predictiveness and uncertainty-based attention during associative learning to automatic and controlled processing. Automatic processing does not require as much attention as controlled processing and is assumed to have unlimited capacity. Its primary goal is to deal with the detection of stimuli that no longer warrant controlled processing because learning about them is complete (Pearce & Mackintosh, 2010). According to Mackintosh (1975), the stimuli that are most likely to be selected for automatic attentional processing are those that have proven to be reliable in the past. Controlled processing requires attention and deliberate effort to the task at hand. Thus, it is essential for learning to occur. The goal of controlled processing is to allocate attention to stimuli for which learning is incomplete. Pearce and Hall (1980) argued that since controlled processing has limited capacity, this type of attention should be directed to stimuli whose outcomes are unpredictable and not to stimuli whose outcomes are already known. The Pearce and Mackintosh hybrid model, therefore, accounts for both theories by considering that animals and humans have two mechanisms of attention that operate according to different rules. Pearce and Mackintosh suggest this hybrid model is a more accurate account of attentional processes in learning because it includes two specific learning rate parameters with alpha changing according to the Mackintosh rules (choosing the most predictive cue) and a new parameter sigma changing according to Pearce and Hall (learning about uncertain outcomes). Similarly, Le Pelley (2004) has suggested that another way to reconcile these two theories is to view them as describing two different properties of a cue. The Mackintosh (1975) theory can be viewed as measuring the weight of a given stimulus compared to other stimuli (attentional associability), and the Pearce-Hall (1980) theory can be viewed as measuring the rate with which each stimulus will be learned about based on its exposure history (salience associability).

Direct Measures of Attention in Associative Learning

Although there has been much research on attention in associative learning using indirect behavioral measures of attention (Griffiths et al., 2011; Le Pelley & McLaren, 2003; Lucke et al., 2013), none of the early studies used any direct measure of attention. Instead, these studies inferred the role of attention from behavioral measures of changes in cue associability. Recent studies have used both eye-trackers and spatial cueing to directly measure attention during learning. Le Pelley, Beesley, and Griffiths (2011) used an eye-tracker in addition to behavioral measures in a replication of the study by Le Pelley and McLaren (2003). In Phase 1, participants spent more time fixating on cues that were predictive compared to non-predictive. Additionally, this bias in fixation time continued during Phase 2 trials where all cues were equally likely to be predictive of their outcomes (Le Pelley et al., 2011). Thus, these findings suggest that both learning and overt attention were influenced by participants' prior experience of predictiveness. There have been several studies with eye-tracking methods showing that predictive cues receive more attention than non-predictive cues (Beesley et al., 2015; Haselgrove et al., 2010; Hoffman & Rehder, 2010).

Spatial cueing is another method frequently used to directly measure attention in associative learning. Research has consistently shown that responses to targets appearing in an attended location are faster than responses to targets appearing in an unattended location (Posner, 1980; Posner, Snyder, & Davidson, 1980). Le Pelley, Vadillo, and Luque (2013) created a spatial cueing dot probe procedure to determine if an attentional bias toward predictive stimuli and away from non-predictive stimuli occurred during learning. They also wanted to determine whether this attentional process was automatic or controlled. They argued that if the cueing effect observed at a short stimulus onset asynchrony (SOA) reflected a conscious strategy of shifting attention toward a predictive cue, then providing more time to process a cue's predictive status should produce a stronger effect (Le Pelley, Vadillo, & Luque, 2013). To assess this, participants were presented with a pair of shapes containing a predictive cue and a nonpredictive cue. Then, participants were asked to respond to a dot probe that appeared superimposed on top of one of the two shapes by pressing the button that corresponded to the location of the probe. Additionally, they compared an SOA of 250ms and a longer SOA of 1000ms between the presentation of the stimuli and the appearance of the dot probe. If the results showed a cueing effect at the longer SOA of 1000ms, it would indicate a controlled attentional process because having more time would allow participants to deliberately attend to one cue or another. The results suggested that when a dot probe appeared in the location of a previously predictive cue, participants responded faster compared to when the dot probe appeared in the location of a previous non-predictive cue. Additionally, when participants were given more time to process the stimuli (1000ms SOA), the influence of predictiveness on dot probe responding was significantly weakened. This finding implies that the cueing effect that was observed at the short SOA was not a consequence of a controlled process, but rather reflects an automatic process.

Evidence from Mitchell, Griffiths, Seetoo, and Lovibond (2012), who used eye-tracking methods, suggest predictiveness can also be influenced by controlled processes. During Phase 1, participants learned that cues were either predictive or non-predictive of an outcome. After Phase 1 was completed, participants in the *Change* group were told that the cue-outcome relationships were going to be switched, meaning that a cue that was previously a reliable predictor would become non-predictive, and a cue that was previously non-predictive would become a reliable predictor in Phase 2. Participants in the *Continuity* group were the control group and were unaware of the new cue-outcome relationships. Therefore, participants in this group believed the cue-outcome relationships would continue into Phase 2. The results from this study showed that participants in the *Change* group produced a learned predictiveness effect that was opposite of the direction observed in the control group. Specifically, participants in the *Change* group learned more about the cues that were previously non-predictive in Phase 2 compared to cues that were predictive in Phase 1. Using an eye-tracker, Mitchell, Griffiths, Seetoo, and Lovibond (2012) were able to detect that participants in Phase 2 gave more overt attention to the previously non-predictive cues. Additionally, they spent less time attending to the previously predictive cues after the cue-outcome relationships had switched. These findings suggest that predictiveness can be regulated by a controlled attentional process because participants were knowingly transferring their attention to the previously non-predictive cues in Phase 2.

The studies reviewed so far have only addressed cue predictiveness in associative learning. The hybrid models (Le Pelley, 2004; Pearce & Mackintosh, 2010) require an examination of both attentional processes in the same experiment. Beesley, Nguyen, Pearson, and Le Pelley (2015) systematically manipulated both the predictiveness of cues and the uncertainty regarding the outcomes that they were associated with and used fixation times to measure attention. In this study, participants assumed the role of a scientist and their task on each trial was to predict which mutant would be created when a particular pair of chemicals were mixed with a special "goo" substance (Beesley et al., 2015). There were two groups of participants that were assigned to either the Certain condition or Uncertain condition. Predictiveness was manipulated by presenting compounds in which one of the two chemicals in the compound was predictive (perfectly predicts the outcome) and the other chemical was nonpredictive (appeared in both outcomes so it does not predict anything).

In Stage 1, participants in the Certain condition were presented with compound stimuli (pairs of chemicals) that would perfectly predict one of two possible outcomes (a mutant). Participants in the Uncertain condition were presented with compound stimuli where 67% of the time it was associated with one outcome, but the remaining 33% of the time it was associated with the other outcome. In Stage 2, participants in both conditions were presented with the same pairs of chemicals, except in this stage the authors wanted to assess associability for cues that had been predictive and nonpredictive. To test this, all participants were presented with two compounds that were previously seen and two new compounds, both of which predicted new outcomes. After Stage 2, the strength of associations between critical cues (cues that were presented in Stage 1 and Stage 2) and the Stage 2 outcomes were tested using individual cue tests and compound cue tests (Beesley et al., 2015). The results of this experiment suggested that participants spent more time fixating on predictive cues compared to nonpredictive cues in both the Certain and Uncertain conditions. Additionally, participants spent more time fixating on compounds whose outcomes were uncertain compared to compounds whose outcomes were certain. To explain this, Beesley et al. proposed that because participants could not predict the outcome of a trial with enough certainty, they intentionally spent more time exploring the cues in more detail to try to identify additional sources of information so they could more accurately make their predictions.

Luque, Vadillo, Le Pelley, and Beesley (2017) manipulated both the level of cue predictiveness and uncertainty in a single learning task using a dot probe procedure. In Pretraining and Phase 1, participants learned that the cues belonged to an “Up” or “Down” category. Predictiveness was manipulated by presenting compound stimuli in which one cue was predictive and one cue was nonpredictive. The predictive cue in the compound consistently indicated the correct categorization response (p1 always belonged to the Up category) and the non-predictive cue provided no information about the categorization response during these phases (n1 belonged to the Up category half of the time and the other half of the time it belonged to the Down category). Thus, once participants learned which cues were predictive, they could reliably select the correct category. In Stage 2, the same cues were presented but uncertainty was introduced. Uncertainty was manipulated in Phase 2 by presenting compound cues in which the correct response was consistent with prior training 67% of the trials, while the correct response was inconsistent with prior training the remaining 33% of trials. The findings showed that in Stage 1 predictive status of a cue determined the amount of attention given to a cue. There was faster attentional capture for predictive cues compared to non-predictive cues. However, participants made overall slower responses to the dot probe in uncertain compounds in Stage 2 (Luque, Vadillo, Le Pelley, & Beesley, 2017). These results provide further support that attention to cues is rapidly modulated by both predictiveness and uncertain attentional processing during associative learning.

Current Study

There is clearly a fundamental relationship between attention and learning. Mackintosh (1975) proposed that attentional resources are allocated to cues that are most predictive of an outcome. This theory of predictiveness has been studied extensively in animals and humans over the past several decades and there is strong evidence to support this theory. However, the Pearce-Hall (1980) theory suggests the opposite. The theory of uncertainty suggests cues with uncertain outcomes will be attended more than those with certain outcomes so that people can learn about their features to better predict an outcome. The hybrid model offers a more accurate account of attentional processes in learning because it includes two specific learning rate parameters with alpha changing according to the Mackintosh rules (choosing the most predictive cue) and sigma changing according to Pearce and Hall (learning about uncertain outcomes) (Pearce & Mackintosh, 2010). However, in order to support the hybrid theory more research is needed that studies both predictiveness and uncertainty in the same learning task. Additionally, the current literature focuses almost entirely on younger adult associative learning, and there are reasons to believe that these two attentional processes that occur during associative learning may differ for young and older adults.

There is a large body of research showing that older adults are less efficient at acquiring cue - outcome associations than young adults (Mutter, Atchley, & Plumlee, 2012; Mutter, DeCaro, & Plumlee, 2009; Mutter, Haggbloom, Plumlee, & Schirmer, 2006; Mutter & Williams, 2004). For example, Mutter and Williams (2004) investigated differences in young and older adults' detection of response–outcome (R-O) contingencies. In this study, participants were informed that in each trial a triangle would appear on the screen. This triangle would either flash on its own or flash after the participant pressed the spacebar. After each trial, participants had to judge the extent to which pressing the spacebar caused the triangle to flash (Mutter & Williams, 2004). The array of contingency values used in this experiment included .80, .40, 0, -.40, and -.80. The findings of this study suggest an overall decline in older adults' ability to detect response-outcome contingencies because older adults were consistently less accurate in their contingency estimates compared to young adults. Although these studies suggest that age affects the associability of cues, there has been little research on whether this deficit might be due to age–related changes in the attentional processes that interact with associative learning.

Findings from a recent study suggest that although older adults have difficulty with associative learning, there is no decline in their ability to attend to predictive stimuli

(Mutter, Holder, Mashburn, & Luna, 2019). In this study, the researchers alternated the presentation of a category learning task with a dot probe task to assess whether there were age differences in the development of automatic attentional biases to predictive cues. Starting with the dot probe task, a fixation cross was presented on the screen before the stimuli appeared. Participants were encouraged to focus on the fixation cross to perform better on this task. Then, participants were asked to respond to the location of a small white square superimposed on one of the two shapes that appeared on the screen. The stimuli consisted of four squares differing in their color (light or dark green) and the thickness of the diagonal lines inside the shapes (thin or thick lines). Participants responded by pressing either the *Left* or *Right* key corresponding to the location of the probe. After the dot probe task, participants began the category learning task. Again, participants were told they would see the same fixation cross and shapes previously seen. However, now they had to learn which of the two categories, either *Up* or *Down*, was correct for each pair of shapes. Participants used the *Up* and *Down* keys to make their category decisions. During the category learning task participants were given feedback for each response. The results showed that young adults were more accurate than older adults, with young adults showing a mean accuracy of approximately 95% and older adults showing a mean accuracy of approximately 85%. In addition, both young and older adults responded faster to the location of a dot probe that was cued by a predictive stimulus than one that was cued by a nonpredictive stimulus. Mutter et al. (2019) suggest older adults' ability to modulate attention to predictive cues during associative learning does not decline with age. This study is the first that has looked at whether attentional processes during associative learning change in older adults. However, it did not assess older adults' ability to attend to uncertain information in the same way that young adults do.

Although recent findings show that older adults respond in the same way as young adults to predictive cues, it is unclear whether this will also be the case for cues with uncertain outcomes. There is some evidence that older adults may have difficulty with top-down, controlled attentional processes that could also affect their ability to learn about uncertain cue-outcome relationships. Using fMRI, Gazzaley, Cooney, Rissman, and D'esposito (2005) investigated how normal aging affects top-down attentional modulation. In this study, participants assigned to three groups where the control group was told to view the faces and scenes without actively remembering them. The two experimental groups were told to remember faces and ignore scenes or remember scenes and ignore faces as they were presented with a series of images. In a memory task that followed, either a face or scene was presented (depending on the relevant group) and participants had to judge whether each image was previously presented or not. The results of this study showed that older adults displayed a deficit in the suppression of cortical activity that was associated with task-irrelevant representations (Gazzaley et al., 2005). Overall, older adults were significantly less accurate at remembering both faces and scenes compared to younger adults. These findings indicate that older adults show a deficit in controlled attention and therefore may not devote greater controlled attention to cues whose outcomes are uncertain in an associative learning task.

In a recent study, Nassar et al. (2016) investigated how age differences in factors that regulate error-driven learning, such as uncertainty, surprise, and hazard rate, can account for age-related deficits in adaptive behavior. In this experiment, young and older adult participants were instructed to predict where a bucket would drop from a virtual helicopter in order to collect a bag of coins. The participants were supposed to make their decisions based on where the bag dropped on the previous trial. The goal of this task was to place the bucket in a location that the bag would most likely drop to earn the most coins. So, on each trial participants were able to see marked locations of their previous bucket location and also the distance between the previous bucket location to where the bag was actually dropped. The results showed that both young and older adults learned the most when the uncertainty of the bag drop was high. However, there were two interesting differences in their learning data. First, young adults seemed to adjust their learning in response to the level of uncertainty, whereas older adults adjusted their learning in response to the level of surprise. Second, young adults updated their predictions of where to place the bucket to catch the coins more than older adults. Overall, the results suggest that there is an age-related deficit of representations of uncertainty in associative learning (Nassar et al., 2016).

The goal of the current study was to determine whether there are age differences in attention to predictive and uncertain cues in associative learning. This research seeks to: (1) replicate earlier findings that older adults' ability to modulate attention based on the predictiveness of cues is similar to young adults' during associative learning (cf., Mutter et al., 2019) and (2) determine whether cue uncertainty will affect young and older adults' attention in the same way during associative learning. This study addresses these research goals by comparing young and older adults' performance on an associative learning task adapted from Luque et al. (2017), in which both the predictiveness of cues and the uncertainty of cue-outcome relationships are manipulated. Additionally, this study compared the reaction times for predictive and uncertain stimuli between young and older adults. Based on Mutter et al. (2019) findings, we hypothesized that predictive stimuli would capture the attention of YA which would make them very accurate in their category responses in the associative learning task. Additionally, when uncertainty is presented in Phase 2, we expected that category responses for YA would be more accurate for certain cue pairs than uncertain cue pairs. Even when uncertain cue pairs are presented YA should perform above chance level. We expected that OA would perform similarly to YA in the accuracy of their category responses. However, when uncertainty was introduced in Phase 2, we were unsure whether or not OA would respond to cue uncertainty. If OA responded to cue uncertainty, they would respond in the same manner as YA. If OA did not respond to cue uncertainty, they would have lower accuracy, performing at or below chance level. Additionally, YA and OA reaction times should be greater for predictive than non-predictive cues. Based on findings from Luque et al. (2017), we expected that YA reaction times would be slower for cue pairs that are uncertain compared to certain cue pairs. Predictions for older adults' reaction times for these cues are more tentative. If older adults do not respond to cue uncertainty their reaction times may be similar for the certain and uncertain cue pairs.

CHAPTER 2

Method

Participants

Twenty-three young adults and 24 older adults were recruited for this study. Young adult volunteers, ages 18-30, were recruited primarily from the Psychological Sciences and Psychology Study Board. Older adult volunteers, ages 60 and over, were recruited from the city of Bowling Green or a bordering county. Primary recruitment occurred via referrals from other WKU laboratories conducting research with older adults if permission to contact was given.

Older adult participants were screened for health problems and cognitive impairment in a preliminary telephone interview. During this interview, they were asked about major medical problems (e.g., stroke or head injury) and medications (e.g., tranquilizers) that could affect cognitive functioning and the telephone version of the Mini-Mental State Exam (cutoff = 17) were administered for purposes of dementia screening. Older adults who failed to meet the criteria for participation were not scheduled for further testing. Those who met the criteria completed the remaining items on the Biographical and Health Questionnaire (BHQ) when they arrived at the laboratory for testing. Young adults also completed the BHQ when they arrived at the laboratory for testing, and the data were used to screen them for medical problems and medications that could affect cognitive functioning. All participants were screened for color blindness using the Ishihara’s Test for Color Deficiency-Concise Edition because visual cues in the experimental task can only be differentiated by color. This took place in the Cognition

Laboratory upon arrival for the study. There were no participants that failed due to color blindness.

Six study board credits were granted to YA participants as compensation. In addition to study board credits, YA received 10 cents per correct trial during Stage 2. The average YA participant payment was $6.30. Older adults received a small stipend ($10/hour) for the contribution of their time to the project in addition to the amount they earned during the learning task. The average OA participant payment was $22.30.

Design and Materials

The learning task used in this study replicated the experimental design and stimuli used by Luque et al. (2017). This study employed a 2 (Group: Young Adult vs. Older Adult) x 2 (Predictiveness: Predictive vs. Nonpredictive) x 2 (Certainty: Certain vs. Uncertain) mixed model design with age group as the only between subjects factor. The dependent variables of this study were reaction time to the dot probe and the accuracy of outcome responses.

A total of eight colored geometric shapes were used as cues (See Appendix A). These cues varied by color and the thickness and shape of "spikes" that extended from the center of the shape. Colors (RGB) and relative luminance for the eight cues were as follows: red (R255, G0, B0; L54), yellow (R230, G230, B51; L217), green (R0, G204, B51; L150), aqua (R51, G255, B255; L212), blue (R0, G128, B255; L110), magenta (R255, G51, B255; L109), brown (R153, G102, B0; L105), and salmon (R255, G128, B128; L155). All cues presented were 3.7cm x 3.7cm and presented on an iMac computer with a 20in display screen. Half of these cues were used in List 1 and the remaining cues were used in List 2. The cue stimuli were presented on a black background in the middle of the horizontal midline of the screen of a Macintosh computer. The distance from the center of one cue to the center of the other subtended at 9.4°. A small, central fixation cross appeared on the horizontal midline of the screen prior to the onset of the cues. The learning task was programmed on an iMac computer using the software SuperLab Pro 5.0.

There were three phases in this experiment starting with Pretraining, which created a baseline for dot probe responses and established the cue–outcome contingencies in an Associative Learning (AL) task. Next, Phase 1 continued the training from Pretraining, which included alternating blocks of the associative learning task and the dot probe task. Lastly, Phase 2 involved a manipulation of the uncertainty of the relationships between cues and the outcomes with which they were paired. See Table 1 for a full design of the experimental task. The Pretraining phase included one block of the dot probe task and six blocks of an AL task with each block containing eight trials. For the dot probe task, after an SOA of 250 ms, the probe appeared superimposed in the center of one of the cues. This probe remained on the screen until participants made the correct response (left arrow key for a probe presented on the left; right arrow key for a probe on the right).

For the associative learning (AL) task in Pretraining and Phase 1, participants were asked to make either an UP or DOWN categorization response on each trial. Table 1 shows the correct response to each of the eight cue compounds that were presented. Each compound contained one predictive cue (P1 or P2) and one nonpredictive cue (N1 or N2). The predictive cue within a compound provided reliable information about what category that particular compound belonged to, whereas the nonpredictive cue did not provide any useful information about category membership.

During Phase 1 and Phase 2, the AL and dot probe tasks were presented as independent, alternating blocks. For example, the first block of each phase started with the dot probe task; the next block was the AL task; the next block returned to the dot probe task, and so on. In both tasks, feedback was provided after every response. In Phase 1, there were 8 blocks consisting of 16 dot probe trials and 7 blocks consisting of 16 AL trials. In Phase 2, there were 8 blocks consisting of 16 dot probe trials and 8 blocks consisting of 12 AL trials. In the AL task of Phase 2, one of the two compound cues maintained a consistent relationship with the outcome as previously learned (i.e., P1N1 belonged to the UP category). The other compound transitioned to an uncertain relationship with the previously learned AL response, R2. For example, throughout Pretraining and Phase 1 P2N2 belonged to the DOWN category. However, in Phase 2 the correct response for this compound was DOWN on two-thirds of the trials, and UP was the correct response on the remaining one-third of trials.

Table 1. *Experimental design table.*

<table>
<tr><th colspan="2"><u>Pretraining</u></th><th colspan="2"><u>Phase 1</u></th><th colspan="2"><u>Phase 2</u></th></tr>
<tr><td>Dot Probe</td><td>Categorization</td><td>Dot Probe</td><td>Categorization</td><td>Dot Probe</td><td>Categorization</td></tr>
<tr><td rowspan="5">1 Block x 16 Trials</td><td>6 Blocks x 8 Trials</td><td rowspan="5">8 Blocks x 16 Trials</td><td>7 Blocks x 16 Trials</td><td rowspan="5">8 Blocks x 16 Trials</td><td>8 Blocks x 12 Trials</td></tr>
<tr><td>P1N1→R1</td><td>P1N1→R1</td><td rowspan="2">Certain Compound
P1N1→R1</td></tr>
<tr><td>P1N2→R1</td><td>P1N2→R1</td></tr>
<tr><td>P2N1→R2</td><td>P2N1→R2</td><td rowspan="2">Uncertain Compound
P2N2→R2 (67%)
P2N2→R1 (33%)</td></tr>
<tr><td>P2N2→R2</td><td>P2N2→R2</td></tr>
</table>

Procedure

Participants were tested individually, and each session lasted no more than two hours. Testing in all experiments took place in the Cognition Laboratory at Western Kentucky University and all participants experienced the following sequence of events. They were informed of the purpose and nature of the experiment when they arrived at the laboratory. Next, they were asked to sign a witnessed informed consent form, completed the Cognition Laboratory Biographical and Health Questionnaire, and completed the color blindness screening process. Then, participants completed the experimental task followed by several basic cognitive ability tests. Prior to each of the tasks, participants were given detailed instructions and an opportunity to ask questions about the procedure.

For the experimental task, participants were instructed that they were going to play a category game consisting of two tasks and that this game was designed to examine their learning skills. First, participants were instructed to perform a target location task in which they had to respond as quickly as possible to the location of a small white square appearing on top of one of the two shapes presented on the screen. To make their response, participants used the keys marked LEFT and RIGHT on the keyboard. Participants were encouraged to keep their eyes fixed on the cross in the center of the screen and ignore the colored shapes. Additionally, participants were told there were a few trials in which the colored shapes and the white square would not appear. On these trials, a small arrow pointed either right or left and this took the place of the cross in the center of the screen. After completing the target location task, they were given instructions for the AL task which was called the categorization task. In this task, participants were instructed to learn which category, either UP or DOWN, was correct for each pair of shapes. Participants indicated their category decisions by using the keys marked UP and DOWN. There was an initial fixation period for 500ms before the stimuli appeared on the screen. Then, participants were given 250 ms before a prompt appeared on the screen that said, “UP OR DOWN?”. There was no time limit for participants to make their responses, so the prompt remained on the screen until they made their response. Immediately after they made their response, participants received feedback on whether they chose the correct or incorrect category. The message that appeared for a correct response said, “That is correct!” and the message for an incorrect response said, “ERROR! The correct response was (UP/DOWN)”. Feedback was presented for 1 s and followed by an intertrial interval of 1 s. Following the first target location task and the first categorization task of Pretraining, participants were told that for the remainder of the experiment, they would continue to do the target location task and the categorization task in an alternating sequence. The beginning of each task was announced on the screen and participants were reminded of the appropriate responses for the task.

In addition to the experimental task, all participants received several tests used widely in cognitive aging research to measure specific cognitive abilities. Working memory was measured using the WAIS-III Digit Symbol Substitution (Wechsler, 1997) and the computer-based Reading Span test (Salthouse & Babcock, 1991). Verbal knowledge was measured by the Advanced Vocabulary Test (Ekstrom, French, & Harman, 1979). Controlled attention was measured using the Stars Counting Test (De Jong & Das Smaal, 1990). Associative learning and memory were measured by the Conditional Associative Learning test (Levine, Stuss, & Milberg, 1997). Concept learning and reasoning processes were measured by the computer-based Wisconsin Card Sorting Test (Heaton et al., 1993). These measures would have been used in correlational analyses to determine whether they explained variance over and above the variance associated with age in experimental task performance. After completing all of the tasks, participants were compensated, fully debriefed and offered an opportunity to ask questions. The full session took no longer than 2 hours but varied in time depending on personal speed.

CHAPTER 3

Results

Data Preparation

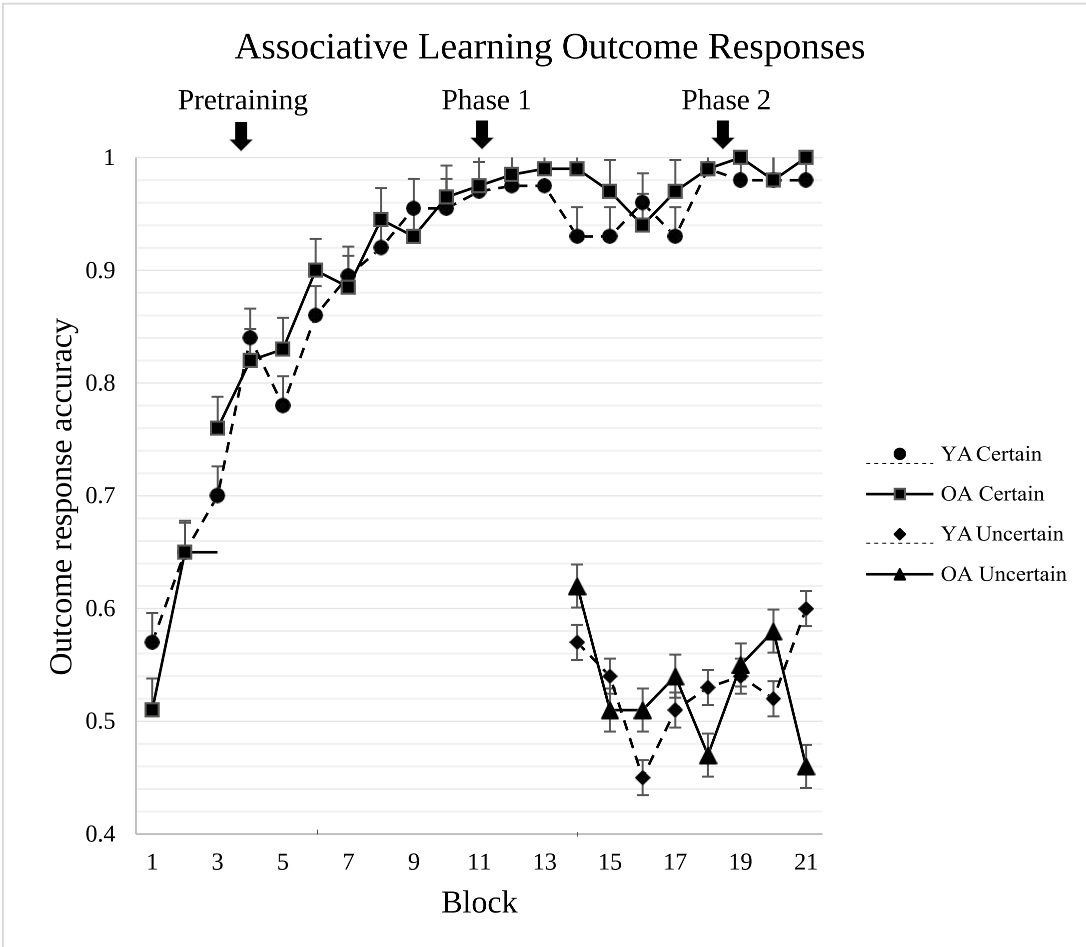
For the AL task, participants who did not reach 60% accuracy for their outcome responses were removed from data analysis. As a consequence of this criterion, 3 young adults and 3 older adults were removed from the analysis. After removing those participants, there were 22 young adult participants and 22 older adult participants used for the data analysis. For the analysis of the reaction times (RT) in the dot probe task, trials in which responses were very fast (under 150 ms) or very slow (over 1500 ms) were removed from the analysis. Similar to Mutter et al. (2019), we computed the median RTs for each participant (for predictive and nonpredictive trials) for every block. The primary data analyses were conducted using median RTs. However, because of the overall speed differences between YA and OA participants, whenever there were any interactions with Group, we analyzed facilitation ratios in addition to median RTs to determine whether the effect still existed after controlling for these age-related speed differences. The facilitation ratios were computed by subtracting the median RT for the predictive and non-predictive trials after learning from the median baseline RT for these trials before learning and dividing by the median baseline RT. The median baseline RT was based on dot probe performance in the Pretraining phase before any learning had occurred.

Associative learning. A mixed-model ANOVA with factors of age and block was used to determine if there was an age difference in the accuracy of outcome responses in Pretraining and Phase 1. Young and older adults' mean category prediction accuracy across blocks is shown in Figure 1. For the Pretraining phase, the 2 (Group: YA vs OA) × 6 (Block: 1-6) mixed-model ANOVA showed a significant main effect of block, F(5, 210) = 21.43, MSE = 6640.49, $p < .001$, η_p^2= .34, and a nonsignificant interaction of Block × Group, F(5, 210) = .80, MSE = 248.83, p = .55, η_p^2= .02. Lastly, there was no significant effect of group, F(1, 42) = .03, MSE = 52.30, p = .86, η_p^2= .001 Thus, both YA and OA became more accurate in their category predictions over time, reaching approximately 85-90% accuracy by the end of Pretraining.

For the Phase 1 data, the 2 (Group: YA vs OA) × 7(Block: 1-7) mixed-model ANOVA revealed a main effect of block, F(6, 252) = 8.08, $p < .001$, MSE = 545.06, η_p^2= .16, indicating that accuracy improved over blocks for both groups. There was a nonsignificant interaction of Block x Group, F(6, 252) = .50, MSE = 33.86, p = .81, η_p^2= .01, and no significant main effect of group, F(1, 42) = .09, MSE = 61.38, p = .76, η_p^2= .002. Both YA and OA reached approximately 97-99% accuracy in their category predictions, which demonstrates that both groups learned the rule that predicted category membership by the end of Phase 1.

For the Phase 2 data, a mixed-model ANOVA with factors of age, block, and certainty was used to determine how cue uncertainty affected the accuracy of outcome responses of young and older adults. The 2 (Group: YA vs OA) × 8 (Block: 1-8) × 2 (Certainty: Certain vs Uncertain) mixed-model ANOVA did not show a main effect of block, F(7, 294) = 1.78, MSE = 265.59, p = .09, η_p^2= .04, but there was a main effect of Certainty, F(1, 40) = 567.43, MSE = 350018.13, $p < .001$, η_p^2= .93, indicating that participants were more accurate in their category predictions for cues that were certain compared to uncertain. As shown in Figure 1, both YA and OA category predictions remained high for cues that were certain, but both YA and OA category predictions dropped to chance level for cues that were uncertain. There were two significant interactions including a Block × Group interaction, $F(7, 294) = 2.5$, $MSE = 372.64$, $p = .02$, $\eta_p^2 = .06$ and a Block x Certainty interaction, $F(7, 294) = 2.57$, $MSE = 397.18$, $p = .014$, $\eta_p^2 = .06$. Figure 1 shows the Block x Group interaction, where in the beginning of Phase 2 there is not a significant difference in YA and OA outcome response accuracy. However, in the last block of the Phase 2, OA outcome response accuracy is worse than YA. Additionally, the Block x Certainty interaction suggests that the accuracy of outcome responses over blocks for certain cues differs significantly to the accuracy of outcome responses over blocks for uncertain cues. Overall, the accuracy of outcome responses for uncertain cues is much worse than the accuracy of outcome responses for certain cues. The remaining main effect and interactions were not significant: Group, $F(1, 42) = .26$, $MSE = 153.35$, $p = .61$, $\eta_p^2 = .01$; Certainty x Group, $F(1, 42) = .74$, $MSE = 454.18$, $p = .40$, $\eta_p^2 = .02$; Block x Certainty x Group, $F(7, 294) = 1.47$, $MSE = 226.96$, $p = .18$, $\eta_p^2 = .03$.

Figure 1. *Mean percent correct responses for young and older adults in the AL categorization task across blocks.*



Dot probe task. For the Phase 1 dot probe task, a 2 (Group: YA vs OA) × 2 (Predictiveness: Predictive vs Non-predictive) mixed-model ANOVA was conducted to analyze age differences in the predictiveness effect. Young and older adults' mean reaction times for Phase 1 are shown in Figure 2 and Figure 3, respectively. This analysis showed a main effect of predictiveness, $F(1,42) = 37.51$, $MSE = 77973.41$, $p < .001$, $\eta_p^2 = .47$. Thus, RTs were faster for predictive cues compared to non-predictive cues. In addition, there was a significant Predictiveness × Group interaction, $F(1,42) = 13.10$, $MSE = 27238.12$, $p = .001$, $\eta_p^2 = .24$. To determine whether this interaction was simply due to age-related differences in processing speed, we analyzed the facilitation ratios which revealed there was a significant Predictiveness x Group interaction, *F*(1,42) = 6.55, *MSE* = .05, *p* = .014, η_p^2= .13. The Predictiveness x Group interaction suggests there are age differences in the reaction times to predictive and nonpredictive cues. Because the interaction remained after controlling for age-related speed differences, the interaction was analyzed by conducting a simple main effects analysis on the facilitation ratios. These analyses revealing that both young and older adults responded faster to a predictive cue than a nonpredictive cue, YA, *F*(1,21) =10.98, *MSE* = .01, *p* = .003, η_p^2= .34 and OA, *F*(1,21) =26.89, *MSE* = .02, *p* < .001, η_p^2= .56.

For the Phase 2 dot probe task, a 2 (Group: YA vs OA) × 2 (Predictiveness: Predictive vs Non-predictive) × 2 (Certainty: Certain vs Uncertain) mixed design ANOVA was conducted to determine if participants responded faster to a predictive cue than a nonpredictive cue and a certain cue pair than an uncertain cue pair. Young and older adults' mean reaction times for Phase 2 are shown in Figure 2 and Figure 3, respectively. This analysis showed a main effect of predictiveness, *F*(1,42) = 19.86, *MSE* = 22432.78, *p* < .001, η_p^2= .32, indicating that reaction times were faster for predictive cues compared to non-predictive cues, but this effect was qualified by a Predictiveness x Certainty interaction, *F*(1,42) = 4.23, *MSE* = 3111.36, *p* = .046, η_p^2= .09. The simple main effect of predictiveness within certain compounds was significant, *F*(1,43) = 16.63, *MSE* = 21126.50, *p* < .001, η_p^2= .28, as well as the simple main effect of predictiveness within uncertain compounds, *F*(1,42) = 6.57, *MSE* = 4417.64, *p* = .01, η_p^2= .13, however the effect of predictiveness was greater for the certain compounds than the uncertain compounds. The simple main effect of certainty within predictiveness was also significant, *F*(1,43) = 8.48, *MSE* = 4138.77, *p* = .006, η_p^2= .17, showing that for predictive cues, reaction times to cues with certain outcomes were much faster than those with uncertain outcomes. However, the simple main effect of certainty within nonpredictiveness was not significant, *F*(1,43) = .30, *MSE* = 211.73, *p* = .59, η_p^2= .01, showing that for nonpredictive cues, there was no difference in the reaction times for cues with certain and uncertain outcomes. There was also a significant Predictiveness x Group interaction, *F*(1,42) = 4.53, *p* = .04, *MSE* = 5117.05, η_p^2= .10, however, upon analyzing the facilitation ratios, the Predictiveness x Group interaction was not significant, *F*(1,42) = .39, *MSE* = .001, *p* = .53, η_p^2= .01, indicating that the initial significant interaction was likely due to differences in processing speed. There were no other significant main effects or interactions, [Certainty, *F*(1,42) = 2.72, *MSE* = 1239.14, *p* = .11, η_p^2= .06; Certainty x Group, *F*(1,42) = 3.25, *MSE* = 1483.64, *p* = .08, η_p^2= .07; Predictiveness x Certainty x Group, *F*(1,42) = .08, *MSE* = 59.11, *p* = .78, η_p^2= .002].

Figure 2. *Mean Reaction Times for Young Adult Participants in Phase 1 and Phase 2.*

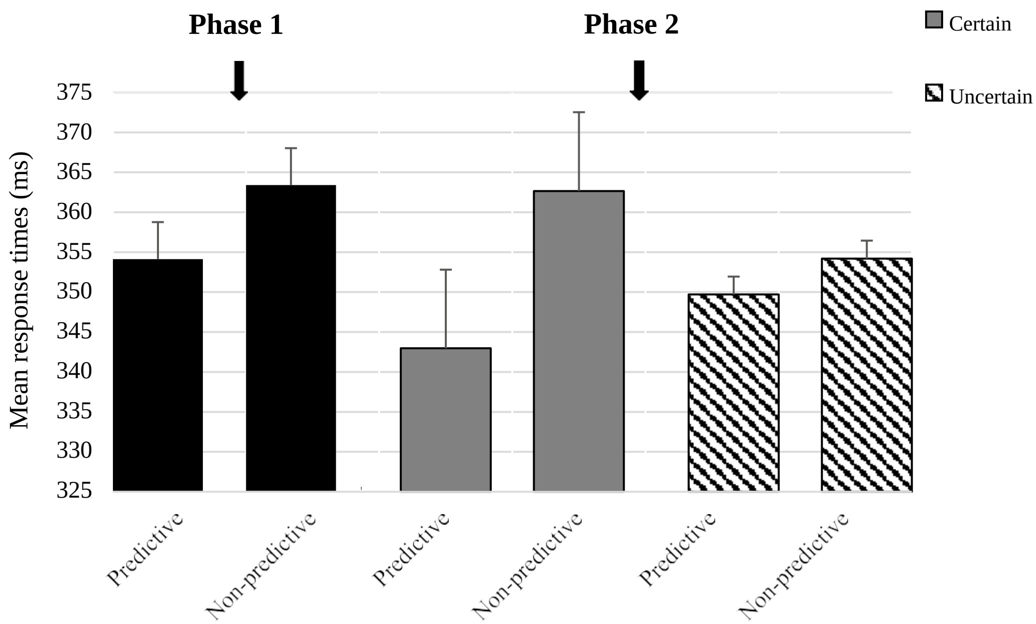
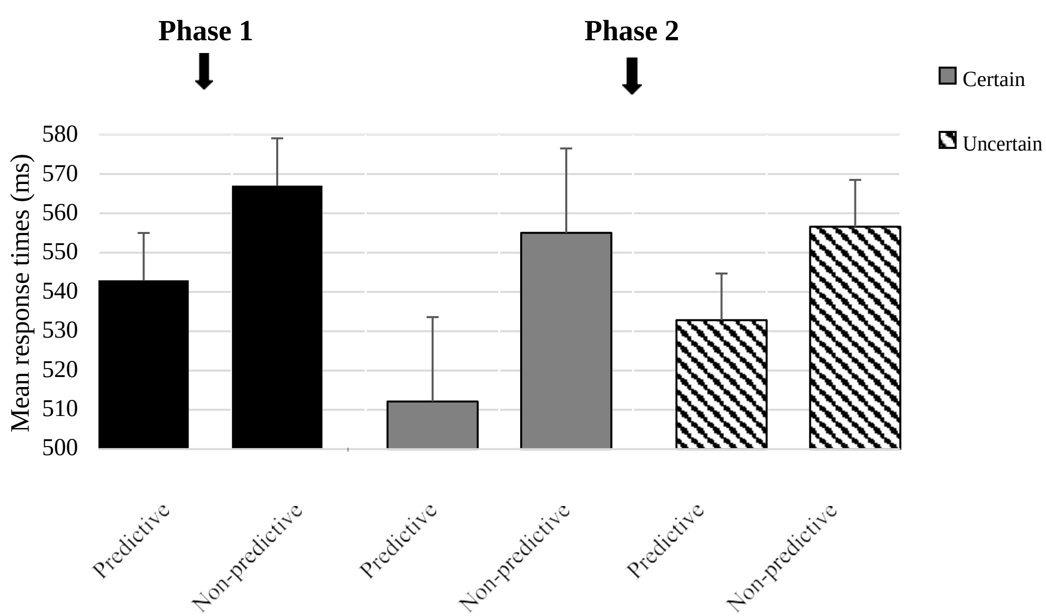


Figure 3. *Mean Reaction Times for Older Adult Participants in Phase 1 and Phase 2.*



CHAPTER 4

Discussion

In this study, we investigated whether there were age differences in the effect of cue predictiveness and uncertainty in associative learning. We manipulated both the predictiveness of the cues and the uncertainty of the cue-outcome relationships within the same associative learning task. During the Pretraining phase both young and older adults became more accurate in their category predictions for cues over blocks. In Phase 1 of the associative learning task, accuracy continued to improve over blocks for both groups. By the end of Phase 1, the data demonstrated that both groups learned the rule that predicted category membership. In Phase 2 of the associative learning task, both young and older adult participants were more accurate in their category predictions for cues that were certain compared to those that were uncertain. In addition, while there was no difference in the outcome response accuracy between young and older adults in the first block of Phase 2, by the last block of this phase older adults' response accuracy was worse than young adults.

The dot probe task assessed participants reaction times to cues that were predictive or non-predictive of category membership cues as well as cues whose outcomes were certain or uncertain. For the dot probe task in Phase 1, the results showed that both young and older adult reaction times for predictive cues were faster compared to their reaction times for non-predictive cues. The dot probe results in Phase 2 again revealed that both groups of participants responded faster to a predictive cue compared to a nonpredictive cue. Additionally, reaction times for certain compounds were faster compared to the reaction times for uncertain compounds. However, there was a significant interaction between predictiveness and certainty indicating that the difference between predictive and non-predictive reaction times were different for certain and uncertain compounds. Specifically, the difference between the predictive and non-predictive reaction times within certain compounds was larger compared to the difference between predictive and non-predictive reaction times within uncertain compounds.

For the associative learning task, we hypothesized that young adults' outcome responses would become more accurate over blocks in Phase 1. Our hypotheses regarding young adult outcomes responses were supported. As shown in Figure 1, the accuracy of young adults' outcome responses was consistently high, reaching above 95% by the end of Phase 1. For older adults, we hypothesized that the accuracy of their outcome responses in Phase 1would also increase. This hypothesis was also supported. As Figure 1 shows, the accuracy of older adults' outcome responses was consistently high, reaching above 98% by the end of Phase 1. Contrary to the Mutter et al. (2019) study, there was no evidence of age differences in learning in Phase 1 of this study. Mutter et al. found significant age differences in category learning, whereas in the current study there were no age differences in the Phase 1 category learning task. This is likely due to the difference in cues. In the current study, the predictive feature of the cues were the colors. In the Mutter et al. study, the predictive feature was the shade of green and the thickness of the lines that were inside the cues. Therefore, it is possible that learning the predict features in the Mutter et al. study was more difficult compared to the current study. Although we didn't predict age differences in Phase 1 outcome response accuracy, we were unsure how uncertainty would affect age differences in Phase 2. We expected that when uncertainty was introduced in Phase 2, the accuracy of young adults' outcome responses for uncertain cues would be worse than the accuracy of their outcome responses for certain cues. The accuracy of young adult outcome responses for certain cues remained above 90%, but the accuracy of their outcome responses for uncertain cues declined to slightly greater than chance level. We also expected that older adults' accuracy for certain cues would be greater than their accuracy of uncertain cues and as expected, the accuracy of older adult's outcome responses for certain cues remained above 90%, but the accuracy of their outcome responses for uncertain cues dropped below chance level. However, older adults' outcome response accuracy in the last block of Phase 2 was worse compared to young adults' outcome response accuracy in this block. Figure 1 suggests this was due primarily to differences in young and older adult accuracy for uncertain outcome responses. This suggests that there could be age differences in associability for the uncertain cues.

For the dot probe task, we hypothesized that both young and older adults would respond faster to a predictive cue than a nonpredictive cue. In addition, we expected young adults to respond faster to a certain cue pair than an uncertain cue pair. However, predictions for older adults responding to cue uncertainty were more tentative. If older adults did not respond to cue uncertainty in the same way as young adults, we expected that their reaction times might be similar for both the certain and uncertain cue pairs. But if older adults did respond to cue uncertainty, we expected that, like young adults, that they would respond faster to a certain cue pair than an uncertain cue pair. Our results showed that young and older adults responded to both predictiveness and uncertainty in the same way. As Figure 2 shows, young adults responded faster to predictive cues compared to a nonpredictive cues. Young adults also responded faster for certain cue pairs compared to uncertain cue pairs. Older adults showed the same pattern. As Figure 3 shows, older adults responded faster to predictive cues compared to nonpredictive cues in both learning phases Interestingly, the Phase 1 results revealed a trend for a larger predictiveness effect in older adult reaction times compared to young adults. Similar to young adults, older adults also responded faster for certain cue pairs compared to uncertain cue pairs, showing that their attention to certain and uncertain cues did not differ from young adults. Thus, our results indicated no significant age difference in the effect of either cue predictiveness or cue certainty on young and older adult's attention in associative learning.

The results from the current study replicate and extend previous findings from Luque et al. (2017) and Mutter et al. (2019) concerning attentional processes in associative learning. The results of both Mutter et al. and the current study extended the Luque et al. finding that predictive cues receive more attention during learning than non-predictive cues to older adults. In Mutter et al. and in both Phase 1 and Phase 2 of the current study, older adults responded in the same way as young adults to predictive and non-predictive cues in the dot probe task. The current study also extended the Luque et al and Mutter et al. dot probe findings by investigating whether there were age differences in the effect of cue uncertainty during associative learning. The findings from Luque et al. showed that young adult participants responded faster to certain cue pairs than uncertain cue pairs. The current study replicated these findings for both young and older adult participants. Obtaining these findings is important because of the lack of research on how age affects attention to uncertain stimuli. The results from the current study provide novel evidence that there are no age differences in attention to certain and uncertain cues during associative learning.

The current study showed that the difference between predictive and non-predictive reaction times for certain compounds was larger compared to uncertain compounds, which Luque et al. (2017) predicted but did not observe. Luque et al. suggests this was a consequence of reduced sensitivity. In the first experiment, Luque et al. did not separate the associative learning and dot probe tasks. So, when they separated the two tasks in Experiment 2 to reduce potential interference, they noticed an overall improvement in reaction time performance. Therefore, Luque et al. believed the response times in Experiment 2 may have been closer to floor, which could have reduced the sensitivity of the experiment to detect the more subtle effect of predictiveness. In addition, young and older adults responded faster to predictive cues from a certain compound compared to those from an uncertain compound but there were no significant differences between the reaction times to non-predictive cues from certain and uncertain compounds. An explanation for these findings could be that reaction times to non-predictive cues between the certain and uncertain compounds. Furthermore, Luque et al. (2017) suggests participants are likely to initially associate the color with category membership. However, when uncertainty is introduced participants are using more cognitive resources to find more information about the cues and the category they belong to. In Phase 2, participants are likely attending to the spikes that extend from the cue and are no longer attending to the predictive feature of color because the color no longer predicts a reliable outcome.

The most important result from the current study is that there were no age differences in attention as a function of cue predictiveness and uncertainty during associative learning. Previous research has mainly focused on young adults when studying attention in associative learning (Le Pelley, Beesley, & Griffiths, 2011; Beesley et al., 2015; Luque et al., 2017). The present study closes this gap in the associative learning literature. Initially, we did not expect older adults to perform the same as young adults when uncertainty was presented in the last phase because previous research has suggested that older adults show a deficit in the ability to update representations of uncertainty (Nassar et al. 2016). However, the results of the current study showed that, at least in the associative learning context used here, older adults performed in the same manner as young adults. A possible explanation for the difference between these findings and those of Nassar et al could be that those researchers used a very different procedure. Specifically, Nassar et al. manipulated relative uncertainty and level of surprise in a predictive inference Helicopter task. The Helicopter task required participants to predict where a virtual helicopter would be located based on where bags had fallen from it previously. In their study, the relative uncertainty was operationalized as the imprecision with which the position of the helicopter could be estimated based on the locations of previous bag drops and the level of surprise was operationalized by prediction errors (Nassar et al., 2016). Overall, the task that participants completed in the Nassar study was more difficult than the task that participants completed in the current study. Considering the differences between the two studies, it is difficult to generalize and compare these findings on uncertainty.

The findings from this study are consistent with both Mackintosh's (1975) theory of predictiveness and Pearce and Hall's (1980) theory of uncertainty Mackintosh claimed that attention will increase to cues that reliably predict an outcome. Furthermore, attention will decrease to cues that not do reliably predict an outcome. Both young and older adults responded faster to a predictive cue compared to a nonpredictive cue, which supports the theory Mackintosh proposed. It is clear that attention to predictive cues does not change with age. Additionally, both young and older adults took longer to respond to an uncertain cue pair than a certain cue pair, which supports the theory Pearce and Hall proposed. Pearce and Hall claimed that people will allocate more attention to cues whose outcome are uncertain, and that attention will decrease to cues whose outcomes are certain. In doing so, the increased attention to cues that are uncertain will allow for more learning to occur. This kind of attention can be described as a controlled process. Controlled attentional processes require deliberate effort and can be used to learn about a stimulus in more depth. In the current study, it appears that both young and older adults gave more attention to uncertain cue pairs than to certain cue pairs, suggesting that they devoted additional attention to these cues in order to learn more about the category to which they belonged. Thus, the results from this study are also consistent with the hybrid model from Pearce and Mackintosh that suggests that although there is substantial support for the two opposing theories, they are ultimately describing different aspects of learned attention to cues. For example, Mackintosh describes the mechanism that controls attention to stimuli that have already been learned. In contrast, Pearce and Hall describe the attentional processing necessary for additional learning about a cue. Considering our results support both theories of attention, they provide support for the idea that there are no age differences in these two mechanisms of attention in associative learning that operate according to different rules

Based on the results of the current study, it is clear that older adults are sensitive to cue predictiveness and uncertainty during associative learning in the same manner that young adults are. However, what we still do not know is how well the attentional response to predictive or uncertain cues relates to associative learning for older adults. According to the Mackintosh (1975) theory of predictiveness, the more predictive a cue is, the more associable it will be. However, the Pearce and Hall (1980) theory of uncertainty suggests that the more uncertain a cue is, the greater its associability will be. However, Mackintosh's theory refers to the subsequent associability of the most predictive cue with a new outcome, whereas Pearce and Hall refer to the associability of the cue within the context of what is happening in the current learning trial. Previous research suggests that predictiveness does improve subsequent learning. For example, Beesley and Le Pelley (2010) gave young adults a serial reaction time task where half of the cues were good predictors of the outcome and the other half were poor predictors of the outcome. After learning these associations, all cues were paired with new outcomes. The results demonstrated that the rate of learning for the new outcomes was greater for predictive cues compared to nonpredictive cues (Beesley & Le Pelley, 2010). More recently, studies with young adults have measured associability after assessing attentional effects for both predictiveness and uncertainty during learning. Beesley et al. (2015) included an associability test in their study that compared the associability of predictive and nonpredictive cues within certain and uncertain compounds by measuring the rate at which they formed associations with novel outcomes during the last phase of training.

There was greater learning for cues that were previously predictive compared to non-predictive, however effect of uncertainty did not influence the rate of learning. Thus, this finding does not support the Pearce-Hall theory. Recently, Easdale, Le Pelley and Beesley (2019) have suggested that it is the onset of uncertainty that influences the rate of learning. For example, they found that presenting uncertainty unexpectedly in the middle of their experiment in comparison to participants experiencing uncertainty from the beginning of the experiment lead participants to increase their attention to cues, which resulted in greater associability (Easdale, Le Pelley, & Beesley, 2019).

Given the results of the current study, and previous findings of the influence of predictiveness on the rate of learning, we might expect that both young and older adults would show a stronger rate of subsequent learning for cues that were previously predictive compared to cues that were previously non-predictive. Furthermore, if young and older adults are paying more attention to uncertain cues, we might expect that they would both learn outcomes for these cues better. But considering our outcome response accuracy findings at the end of Phase 2 where young adults seemed to track the probability of the outcome for the uncertain cues and older adults did not, it may be that older adults did not use the uncertainty information as well as young adults. Thus, it is important for future aging studies of associative learning to include measures of associability to better understand how this is influenced by cue uncertainty.

Future research should also include the use of eye-tracking similar to Beesley et al. (2015) to obtain a better understanding of the specific aspects of uncertain cues that participants are paying attention to. By using eye-trackers it is possible to directly measure the amount of time a participant fixates on a predictive cue vs. a nonpredictive cue or a certain cue pair vs an uncertain cue pair. Additionally, it is possible to measure the amount of attention given to a predictive or nonpredictive cue within a certain or uncertain cue pair. This is important because there is very little research on attention and cue uncertainty that includes older adults, so this could add to our understanding of age-related deficits in associative learning. Another opportunity for future research would be to use stimuli that are more complex. The stimuli used in this study only differed in the color and thickness of spikes that extended from the center of each shape. These stimuli were used because they were similar to the stimuli that Luque et al. (2017) and Mutter et al. (2019) used. However, stimuli that are more complex or a procedure that includes a more complex learning scenario (e.g., Nassar et al., 2016) would increase the external validity because it would more closely resemble something that both young and older adults experience in their everyday lives. For example, you could use a scenario in which individual cues are types of pills or medication that vary in their size, shape, or color. The outcomes that are associated with these cues could be that they treat different symptoms. Using more complex stimuli in future studies could uncover more information about the effects of predictiveness and uncertainty of cues on the rate of associative learning

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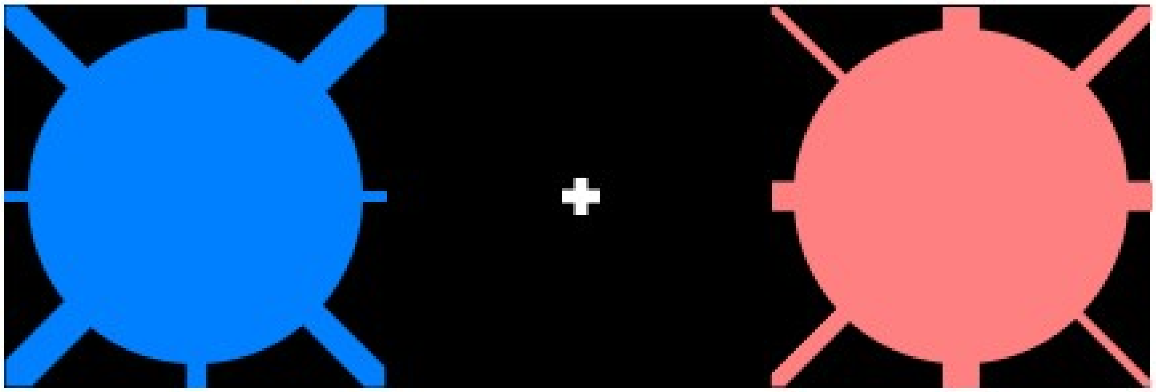
Appendix A



Above is an example of a compound stimuli that was used during the learning task. In this example, blue would be the predictive cue and salmon would be the nonpredictive cue. So, if participants were to see this, they would know that because blue is predictive of a category (i.e. Up) they should respond by pressing the key that corresponds to the Up category. However, salmon is nonpredictive so it occurs in the Up category half of the time and in the Down category the other half of the time.