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Aging and Retrospective Revaluation of Causal Learning

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Abstract

In a two-stage causal learning task, young and older participants first learned which foods presented in compound were followed by an allergic reaction (e.g., STEAK - BEANS → REACTION) and then the causal efficacy of one food from these compounds was revalued (e.g., BEANS → NO REACTION). In Experiment 1, unrelated food pairs were used and although there were no age differences in compound or single cue – outcome learning, older adults did not retrospectively revalue the causal efficacy of the absent target cues (e.g. STEAK). However, they had weaker within – compound associations for the unrelated foods and this may have prevented them from retrieving the representations of these cues. In Experiment 2, older adults still showed no retrospective revaluation of absent cues even though compound food cues with pre-existing associations were used (e.g., STEAK - POTATO) and they received additional learning trials. Finally, in Experiment 3, older adults revalued the causal efficacy of the target cues when small, unobtrusive icons of these cues were present during single cue revaluation. These findings suggest that age – related deficits in causal learning for absent cues are due to ineffective associative binding and reactivation processes.

The ability to detect the causal structure of the environment and adapt behavior accordingly is a central topic in studies of human learning. In a typical causal learning task, participants are asked to discover the relationship or contingency between a cue (or cues) and an outcome. Contingency information is conveyed over a series of discrete learning trials in which the cue and outcome are paired or unpaired. In a generative causal contingency, outcome occurrence is more likely in the *presence* of the cue than in its absence and in a preventative causal contingency, outcome occurrence is more likely in the *absence* of the cue than in its presence. Research has consistently shown that age differences in causal learning are greater for preventative than generative causal contingencies, suggesting that older adults may have a selective deficit in their ability to acquire causal information about absent cues (Mutter, Haggbloom, Plumlee, & Schirmer, 2006; Mutter & Pliske, 1996; Mutter & Plumlee, 2009; Mutter, DiCaro, & Plumlee, 2009; Mutter & Williams, 2004). If this is the case, age differences should also be observed in other causal scenarios that require learning about absent events. We addressed this issue in the following study by examining whether there are differences in young and older adults' retrospective revaluation of absent cues.

Retrospective revaluation is a cue interaction effect that occurs when the causal efficacy of a cue that is not physically present changes in light of new causal information about other

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cues. Two types of retrospective revaluation, recovery from overshadowing and backward blocking, have received considerable research attention (e.g., Aitken, Larkin, & Dickinson, 2001; Dickinson & Burke, 1996; Larkin, Aitken, & Dickinson, 1998; Wasserman & Berglan, 1998). To illustrate, suppose you eat a potato (Cue A) topped with cheese (Cue B) and experience an allergic reaction (AB+). This leads you to adjust the causal efficacy of both food cues upward. Subsequently, you eat a potato by itself without the cheese, experience no allergic reaction (A-), and therefore adjust the causal efficacy of this cue downward. Recovery from overshadowing occurs if you also adjust the causal efficacy of the absent cue, cheese (B), upward. On the other hand, suppose that when you eat a potato without the cheese, you again experience the allergic reaction (A+). Backward blocking occurs if you then adjust the causal efficacy of the absent cue (B) downward. Recovery from overshadowing is stronger and more reliable than backward blocking (Larkin et al., 1998), but both of these cue interaction effects have been observed in animals and humans (Miller & Matute, 1996; Wasserman & Berglan, 1998).

The associative learning theory developed by Rescorla and Wagner (1972) and its variations (e.g., Van Hamme & Wasserman, 1994) have been applied with great success to many aspects of human causal learning, including retrospective revaluation (see Shanks, 2010, for a recent review). The central idea in this theory is that changes in the associative value (i.e., causal efficacy) of cues are driven by prediction error that is generated by the unexpected occurrence or unexpected nonoccurrence of an outcome. The associative value of a cue that is physically present in the environment *increases* when it is followed by an unexpected outcome and *decreases* when it is not followed by an expected outcome. This error-driven learning process operates somewhat differently for cues that are not physically present. Specifically, the associative value of an absent cue changes only when its occurrence is *expected*, which requires indirect activation of its memory representation via an associative link with the context or with other discrete cues that are physically present (Aitken et al., 2001; Dickinson & Burke, 1996). The associative value of the absent, but expected cue then changes in a direction opposite to that observed for a cue that is physically present; i.e., its associative value *decreases* when it is followed by an unexpected outcome and *increases* when it is not followed by an expected outcome (Van Hamme & Wasserman, 1994).

This associative learning theory accounts for retrospective revaluation in the following way. During the initial stage of learning, associations are formed between the two cues presented in compound (e.g., AB) and between these cues and the outcome (Dickinson & Burke, 1996). In the subsequent stage when cue A is presented alone, it indirectly activates the representation of cue B via its associative link with this cue. The associative value of the absent, but expected cue B then changes in a direction opposite to that of cue A. By this account, cue – cue or *within-compound* associations play a critical role in retrospective revaluation. There is considerable support for this idea. For example, retrospective revaluation is correlated with memory for within – compound associations (e.g., Chapman, 1991; Wasserman & Berglan, 1998) and manipulations that strengthen or weaken these associations have parallel effects on retrospective revaluation (e.g., Aitken et al., 2001; Dickinson & Burke, 1996; Larkin et al., 1998; Mitchell, Killedar, & Lovibond, 2005).

One of the most consistent findings in cognitive aging research is that older adults perform less effectively than young adults on tasks that require forming and retrieving associative links between events. A recent review by Old & Naveh-Benjamin (2008) shows that this age-related associative deficit is quite broad, encompassing a variety of explicit learning and memory tasks (e.g., paired-associate learning, cued recall, yes-no recognition, associative recognition) and multiple types of associations (e.g., two items, an item and its context, or two contextual features). Likewise, age has a detrimental effect on implicit learning tasks such as higher-order sequence learning (e.g., Howard, Howard, Japikse, DiYanni,

Thompson, & Somberg, 2004) that involve extracting complex temporal and predictive relationships between co-occurring stimuli. Given the importance of associative processes in causal learning, it seems likely that this extensive age-related associative deficit is also responsible for the changes that have been observed in older adults' causal learning (Mutter, et al., 2006; Mutter & Pliske, 1996; Mutter & Plumlee, 2009; Mutter, et al., 2009; Mutter & Williams, 2004).

A broad-based associative deficit could negatively impact older adults' ability to acquire and use cue – cue, context – cue, or even cue – outcome associations in causal learning. To our knowledge, there has been no research that has focused directly on older adults' use of cue – cue or context – cue associations in causal learning tasks. However a number of studies have shown that age differences are small and sometimes non-existent in tasks that involve learning predictive and causal relationships for physically present cues and outcomes, but these differences are large and pervasive in tasks that involve learning relationships for absent cues and outcomes. For example, there are no age differences in delay discrimination eyeblink conditioning where discrete CS+ and CS– overlap in time with the US, but older adults are impaired at trace discrimination eyeblink conditioning where these cues do not overlap in time with the US (Knuttinen, Power, Preston, & Disterhoft, 2001). Moreover, when age differences are present in causal learning tasks for physically present cues, they can often be eliminated by simple improvements in the learning conditions. This is not the case, however, when these tasks involve absent cues. For example, providing additional learning trials and improving the contiguity between a cue and outcome produces equivalent performance for young and older adults in generative causal learning, whereas the same manipulations improve young, but not older adults' performance in preventative causal learning (Mutter et al., 2009; Mutter & Williams, 2004). Similarly, age differences in feature positive (FP) discrimination learning (i.e., the occurrence of a distinctive feature predicts reinforcement) are eliminated after practice with FP discrimination, but these differences persist in feature negative (FN) discrimination learning (i.e., the nonoccurrence of a distinctive feature predicts reinforcement) after practice with FN discrimination (Mutter, et al., 2006).

In each of the predictive and causal learning tasks where pervasive age differences are observed, information that is critical for accurate performance comes from trials in which predictive cues are absent. For cue – outcome learning to occur in these tasks the representations of the missing cues must be activated indirectly via their associations with either the background context (context – cue associations) or with other discrete cues (i.e., cue – cue associations) that are physically present during the trial. This, in combination with the evidence that older adults have less difficulty acquiring basic cue – outcome associations for predictive cues that are physically present, suggests that the primary associative deficit in older adults' causal learning may be a reduced ability to acquire and use context – cue and cue – cue associations to indirectly activate the representations of absent cues.

In the present study, we used a retrospective revaluation task to further explore age differences in causal learning for absent cues. This task allowed us to separately assess the contribution of age-related changes in cue – cue and cue – outcome associative processes to this decline. In three experiments, participants played the role of an allergist who is attempting to learn whether certain foods cause an allergic reaction in a hypothetical patient (cf. Van Hamme & Wasserman, 1994; Dickinson & Burke, 1996; Larkin et al., 1998). During initial compound cue training, the patient ate meals with two foods and in subsequent single cue training, the patient ate meals with one food from the earlier meals. In both of these stages of acquisition training, participants predicted whether the meals eaten by the patient did or did not cause an allergic reaction and then received feedback on the actual outcome. After completing acquisition training, participants judged the causal

efficacy of the individual food cues and then recorded how confident they were in their memory for the food pairs in the compound cues.

Two general predictions about older adults' retrospective revaluation performance can be made based on the apparent differences in their ability to acquire the various associations in causal learning. First, if the acquisition of cue - outcome associations is relatively unaffected by aging, older adults should readily learn the causal efficacy of the compound food cues that are presented during compound cue training and should also revalue the causal efficacy of the single food cues that are presented during single cue training. However, an age-related decline in cue - cue associative processes should lead to the formation of weaker associations between the two foods during compound cue training and prevent older adults from using these associations to indirectly activate the representation of absent food cues during single cue training. Consequently, they should be less likely to revalue the causal efficacy of these missing cues. This specific age-related associative deficit should also be apparent in poorer memory for the within-compound associations of the compound food cues presented in the first training stage.

Experiment 1

Method

Participants—Different groups of young and older adults participated in each of three experiments for this study. All of the young participants were recruited from psychology classes at Western Kentucky University and received course credit or a small monetary stipend for their participation; all of the older participants were recruited from the community and were paid a small stipend for their participation. None of the participants reported histories of neurological or psychological illness, none were using medications known to affect cognitive ability, and all reported good health for their age group. Twenty-seven young adults (7 male, 20 female) and twenty-seven older adults (7 male, 20 female) participated in the current experiment.

Biographical and cognitive ability data for these two groups are shown in Table 2. As is typically observed in studies of adult aging, older adults had completed more education than young adults, $F(1, 52) = 17.07, p \leq .001$, and had higher Mill Hill Vocabulary scores, $F(1, 52) = 15.88, p \leq .001$. However, they had lower scores than young adults on Digit Symbol Substitution (DSS), $F(1, 52) = 70.29, p \leq .001$, and Digit Symbol Incidental Learning (DSIL) test, $F(1, 52) = 11.63, p \leq .001$, they completed fewer categories in the Wisconsin Card Sorting Test (WCST), $F(1, 52) = 25.47, p \leq .001$, and they had marginally lower scores on the Reading Span test, $F(1, 52) = 3.82, p \leq .06$.

Stimuli and Design—We used a two-stage recovery from overshadowing design to maximize the probability of obtaining a retrospective revaluation effect. This design was first reported by Larkin et al. (1998) and is illustrated in Table 1. During compound cue training, participants were trained concurrently on three causal contingencies. Compound cues from the revaluation (AB+, CD+, EF+) and control (IJ+, KL+, MN+) contingencies were followed by an outcome and, to encourage participants to attend to and learn these contingencies, cues from a filler (RS-, TU-, VW-) contingency were not followed by the outcome. During single cue training, individual treatment cues from the revaluation contingency (A-, C-, E-) were presented without the expected outcome, so the causal value of these cues and the absent revaluation target cues (B, D, F) should change. No cues from the control contingency were presented during this stage of acquisition and single cues from the filler (R-, T-, V-) contingency were again presented without the outcome, so the causal value of cues from these two contingencies should not change. Finally, to encourage participants to attend to and learn the single cue contingencies, three novel irrelevant cues

(X+, Y+, Z+) followed by the outcome were presented. The test for retrospective revaluation immediately followed single cue training. Each individual treatment and target cue was presented for a rating of its causal efficacy in producing the outcome. The retrospective revaluation effect is indicated by an increase in test ratings for target cues from the revaluation contingency (B, D, F) relative to target cues from the control contingency (J, L, N).

Twenty-one common foods were used as cues (i.e., lemon, butter, beans, chicken, peach, carrots, rice, steak, tomato, pear, bread, cake, cheese, banana, coffee, garlic, ham, ice cream, mushrooms, squash, jam). Nine foods were randomly selected and assigned to each of the three treatment cues in the revaluation, control, and filler contingencies. Another nine foods were randomly selected to be target cues. The remaining three foods served as irrelevant cues during single cue training. Each target food cue was paired with each treatment cue in each contingency, thereby creating nine different sets of nine compound food cues. Three young and three older participants were randomly assigned to each of the nine sets of cues.

The retrospective revaluation task was programmed in PsyScope and stimuli were shown on the screen of an Apple monitor. During compound and single cue training, cues appeared centered horizontally and vertically on the screen. These stimuli were created in the following way. High-resolution color images of the 21 foods were obtained from a variety of sources on the Internet. The background was removed from each picture and the image was scaled and cropped to a 4.72" square and inserted into a PowerPoint slide. The name of the food was typed in 24 point Helvetica font directly under the center of the image. The slide was then saved as a QuickDraw picture. The resulting single food/name picture was centered in the middle of a 10.0" wide by 7.5" high frame. Compound food/name images were created in the same way by placing two food/name images side-by-side such that when saved as QuickDraw pictures they were centered in the middle of a frame with the same dimensions as the single cues.

Outcome feedback presented during compound and single cue training appeared directly above the cues, centered vertically on the screen. These pictures were created in the same way as the cue pictures. The PowerPoint slide for outcome occurrence contained the words "Allergic Reaction" typed in red 24 point Helvetica font centered in the middle of a graphic composed of jagged red lines; the slide for outcome nonoccurrence contained the words "No Reaction" typed in green 24 point Helvetica font centered in the middle of a rectangle with smooth green lines. These outcome images were converted to 4.5" wide × 2.5" high QuickDraw pictures.

Rating scales used to indicate causal efficacy and recognition confidence were shown below the cue, centered horizontally at the bottom of the monitor screen. The rating scale for causal efficacy ranged from 0 (definitely will not) to 4 (possibly) to 8 (definitely will) cause an allergic reaction. This scale was created in PowerPoint using 12 to 20 point black Helvetica font, then converted to a 10" wide × 1.5" high QuickDraw image. The rating scale for recognition confidence ranged from -5 (definitely not seen) to +5 (definitely seen). A 10" wide × 1.5" QuickDraw picture of this scale was created in the same way as the picture of the scale for rating causal efficacy.

Procedure—Participants were tested individually in a single session lasting no more than 2.5 hours. During this time, they completed informed consent procedures, a biographical and health questionnaire, the retrospective revaluation task, and standardized and non-standardized tests of processing speed, incidental associative learning, working memory, semantic knowledge, and category learning (see Table 2). Breaks were given during the session as needed. The retrospective revaluation task included in order, a baseline rating of

the causal efficacy of all 21 food cues, an acquisition phase consisting of compound cue training and single cue training, a test rating of the causal efficacy of all 21 cues, and a recognition test for the compound cues. The instructions for this task are provided in Appendix A.

For the baseline rating, participants were told they would see a series of different foods and that for each food they should rate the likelihood that an ordinary individual would have an allergic reaction after eating the food. The single food cues then appeared in random order and participants rated the likelihood that each would cause an allergic reaction using the causal efficacy rating scale shown below the cue. Participants indicated their ratings by pressing keys located on the third row of the computer keyboard that were labeled with the values from the rating scale. The cues remained on the screen until a rating was provided and there was a 500 ms interval between cues.

The acquisition phase began immediately after participants completed their baseline ratings. Participants were told to imagine that they were allergists who had to learn what foods caused their new patient, “Mr. X”, to have an allergic reaction. They then received six blocks of compound cue training followed by three blocks of single cue training. In each compound cue block, they saw nine compound food cues, three each from the revaluation, control, and filler contingencies, presented randomly. After a compound cue appeared on the screen, participants predicted whether eating the foods would or would not cause an allergic reaction by pressing one of two keys located on the bottom row of the keyboard that were labeled with the response alternatives (i.e., Yes or No). As soon as they made their response, feedback appeared directly above the cue indicating whether the allergic reaction had or had not occurred. The compound cue and outcome feedback remained on the screen for 3 sec at which time the screen was cleared and the next compound cue appeared. Single cue training began immediately after compound cue training without any discernable break. In each of the three single cue blocks, participants saw nine single food cues, three each from the revaluation, filler, and irrelevant contingencies, presented randomly. As before, they predicted whether eating the food would cause an allergic reaction and received immediate outcome feedback. After a three second interval the screen was cleared and they saw the next single cue.

At the end of single cue training, participants rated the likelihood that each of the 21 single food cues would cause an allergic reaction in their patient, Mr. X. For this rating, they were instructed to consider all of the information they had acquired during Mr. X’s daily allergy tests. The single food cues were shown in random order and participants provided their ratings using the same rating scale and response keys as before. The cues remained on the screen until a rating was provided and there was a 500 ms interval between cues.

Finally, participants completed a recognition test for the compound cues they had seen during compound cue training. They were told that they would see several meals comprised of two foods and that they should decide if these foods were previously given together as meals to Mr. X. Participants then saw the nine original compound food cues randomly intermixed with nine novel compounds of the same foods. The novel food compounds consisted of treatment cues from one contingency paired with target cues from a different contingency and these stimuli were created in the same way as the original compound cues. Participants indicated how confident they were that they had or had not seen the original and novel food compounds by pressing keys located on the second row of the keyboard that were labeled with the values from the recognition confidence scale. The food pairs remained on the screen until participants provided their response and there was a 500 ms interval between the pairs.

Results and Discussion

Acquisition—The top panel of Figure 1 shows the percentage of trials in which young and older adults predicted that cues for the revaluation, control, and filler contingencies would produce an allergic reaction for each of the six blocks of compound cue training; the bottom panel shows the percentage of trials in which the two groups predicted that cues for the revaluation, control, and irrelevant contingencies would produce an allergic reaction for each of the three blocks of single cue training. A 2 (Age) $\times$ 6 (Block) $\times$ 3 (Contingency) mixed factorial ANOVA for predicted allergic reactions during compound cue training revealed no effect of age on overall predictions, $F(1, 52) < 1.00$. Predictions varied over block, $F(5, 260) = 32.46$, $MSE = .05$, $p \leq .001$, $\eta^2 = .38$, and this effect differed for young and older adults, $F(5, 260) = 2.51$, $p = .03$, $\eta^2 = .05$. More importantly, for both young and older participants predicted reactions were higher for the revaluation and control contingencies than for the filler contingency [Contingency, $F(2, 104) = 448.91$, $MSE = .08$, $p \leq .001$, $\eta^2 = .90$; Age $\times$ Contingency, $F(2, 104) = 2.52$, $p = .09$, $\eta^2 = .05$], and predictions for these three contingencies diverged in the same way over blocks for both age groups [Block $\times$ Contingency, $F(10, 520) = 71.40$, $MSE = .04$, $p \leq .001$, $\eta^2 = .58$; Age $\times$ Block $\times$ Contingency, $F(10, 520) = 1.28$, $p = .24$, $\eta^2 = .02$].

A 2 (Age) $\times$ 3 (Block) $\times$ 3 (Contingency) mixed factorial ANOVA for predicted allergic reactions during single cue training produced similar results. There was no difference in young and older adults' overall predictions, $F(1, 52) = 1.29$, $MSE = .00$, $p = .26$, $\eta^2 = .02$. Predicted reactions varied over the three blocks of single cue training, $F(2, 104) = 9.56$, $MSE = .04$, $p < .001$, $\eta^2 = .16$, and this effect did not differ for the two age groups, $F(2, 104) = 1.78$, $p = .17$, $\eta^2 = .03$. Predicted reactions were higher for the irrelevant contingency than for the revaluation and filler contingencies for both young and older participants [Contingency, $F(2, 104) = 295.61$, $MSE = .05$, $p < .001$, $\eta^2 = .85$; Age $\times$ Contingency, $F(2, 104) = 1.71$, $p = .31$, $\eta^2 = .02$] and predictions for these three contingencies diverged over blocks in the same way for both groups [Block $\times$ Contingency, $F(4, 208) = 146.54$, $MSE = .04$, $p < .001$, $\eta^2 = .74$; Age $\times$ Block $\times$ Contingency, $F(4, 208) < 1.00$].

Young and older participants showed similar rates of learning during the acquisition phase of the retrospective revaluation task. Moreover, by the end of six blocks of compound cue training, both groups had learned to predict more allergic reactions for cues in the revaluation and control contingencies than for cues in the filler contingency and by the end of the three blocks of single cue training, they had learned to predict more allergic reactions for cues in the irrelevant contingency than for cues in the revaluation and filler contingencies. This outcome is important for two reasons. First, it shows that the young and older adults in this experiment did not differ in their ability to acquire the requisite compound and single cue – outcome associations. Second, because the older adults were clearly able to learn the cue – outcome relationships in the retrospective revaluation design, poor cue – outcome learning can be ruled out as a potential influence on their ability to adjust the causal efficacy of the absent target cues.

Target Cue Ratings—Mean baseline and test ratings for target cues from the revaluation (i.e., B, D, F) and control (i.e., J, L, N) contingencies are shown in Table 3. Retrospective revaluation is indicated by significantly higher test ratings for target cues from the revaluation contingency than for those from the control contingency. However, inspection of the baseline ratings suggested that participants in both age groups gave somewhat higher ratings to the target cues from the revaluation contingency than to those from the control contingency prior to acquisition training. Although this bias is likely due to random variation, we conducted a preliminary 2 (Age) $\times$ 2 (Time) $\times$ 2 (Contingency) mixed factorial ANOVA for baseline and test ratings to determine whether the difference between the

reevaluation and control target cues was significantly greater for test ratings than baseline ratings. This analysis revealed that this was the case; the combination of age and the time at which the ratings were collected affected the size of the difference between the reevaluation and control contingencies [$\text{Age} \times \text{Time} \times \text{Contingency}$, $F(1, 52) = 6.52$, $p = .01$, $\eta^2 = .11$].

A subsequent $2 (\text{Age}) \times 2 (\text{Contingency})$ ANOVA for the target cue baseline ratings indicated that although ratings for the reevaluation cues were higher than those for the control cues, this initial bias did not vary with age [Age , $F(1, 52) < 1.00$, Contingency , $F(1, 52) = 4.36$, $MSE = .29$, $p = .04$, $\eta^2 = .08$; $\text{Age} \times \text{Contingency}$, $F(1, 52) < 1.00$]. The same analysis for the target cue test ratings showed that young adults' overall ratings were higher than those of older adults, $F(1, 52) = 10.38$, $MSE = 5.11$, $p = .002$, $\eta^2 = .17$, and overall ratings for the reevaluation and control contingencies were similar, $F(1, 52) = 2.91$, $MSE = 2.43$, $p = .09$, $\eta^2 = .05$. However, there was a significant interaction between age and contingency, $F(1, 52) = 5.79$, $p = .02$, $\eta^2 = .10$, and an analysis of the simple effect of contingency for each age group revealed that young adults rated target cues from the reevaluation contingency more highly than those from the control contingency, $F(1, 26) = 7.34$, $MSE = 2.79$, $p = .01$, $\eta^2 = .22$, whereas older adults' ratings for these cues did not differ, $F(1, 26) < 1.00$. Thus, young adults retrospectively revalued the absent target cues from the reevaluation contingency, but older adults did not.

Recognition Confidence Ratings—To assess possible age differences in the strength of within-compound associations for the food cues, we compared young and older adults' recognition confidence ratings for the original and novel compounds. These data are shown in Table 4. Older adults were less confident that they had seen the original compound cues, $F(1, 52) = 5.17$, $MSE = 1.72$, $p = .03$, $\eta^2 = .09$, and that they had not seen the novel compound cues, $F(1, 52) = 15.11$, $MSE = 4.34$, $p < .001$, $\eta^2 = .22$, suggesting that they acquired relatively weak within-compound associations for the compound food cues during compound cue training. This finding, combined with the fact that there were no age differences in discrimination of the causal contingencies, suggests that weak within-compound associations could be the source of older adults' failure to retrospectively update the causal value of the absent target cues.

For reevaluation processes to occur during single cue training, presentation of the treatment cues from the original compounds must indirectly activate the representation of the absent target cues via their within - compound associations (cf. Aitkin et al., 2001; Dickinson & Burke, 1996). Age-related weakening of these associations would thus lead to less effective activation and reevaluation of the absent target cues. There are no overt instructions to form associations between treatment and target cues in retrospective reevaluation tasks, so it is perhaps not surprising that our older adults' within - compound associations for these cues were weak. However, age differences are often magnified following intentional associative learning relative to incidental learning (e.g., Naveh-Benjamin, Shing, Kilb, Werkle-Bergner, Lindenberger, & Li, 2009; Spencer & Raz, 1995), suggesting that overt instructions to form within - compound associations would not necessarily eliminate the age - related impairment in retrospective reevaluation. On the other hand, age differences in associative learning and memory are reduced and sometimes even eliminated for events with pre-existing associations (for a review, see Kausler, 1994). Therefore, older adults may be able to retrospectively revalue absent target cues if there are already within - compound associations between these cues and the treatment cues. Under these conditions, the presented treatment cues should activate the absent target cues allowing reevaluation to occur. We tested this hypothesis in Experiments 2a and 2b using compound food cues constructed of foods that are commonly seen or eaten together (e.g., steak - potato, pie - ice cream).

Experiment 2a

Method

Participants—Twenty-seven young adults (11 male, 16 female) and twenty-seven older adults (12 male, 15 female) participated in Experiment 2. Biographical and cognitive ability data for the two groups are shown in Table 2. Age differences in these data were similar to those in Experiment 1 [Education, $F(1, 52) = 5.91, p \leq .02$; Vocabulary, $F(1, 52) = 12.88, p \leq .001$, DSS, $F(1, 52) = 58.05, p \leq .001$; DSIL, $F(1, 52) = 15.88, p \leq .001$; WCST, $F(1, 52) = 27.59, p \leq .001$, Reading Span, $F(1, 52) = 3.17, p \leq .08$].

Stimuli and Design—The compound food cues for this experiment were composed of food pairs with pre-existing associations selected from a list of food items commonly seen or eaten together (en.wikipedia.org/wiki/List_of_food_pairs). The food pairs were: steak – potato, bacon – eggs, bread – butter, pie – ice cream, cheese – crackers, peas – carrots, tea – lemon, beans – rice, and lettuce – tomato. All but two of the pairs contained at least one food item that was used in Experiment 1. Because the associations between almost all of these food pairs were stronger in the direction listed above than in the reverse direction, the first word in each pair was used as the treatment cue and the second as the target cue. Each of the nine associated food pairs was counterbalanced over the nine compound cues in the revaluation, control, and filler contingencies, creating nine different cue sets. The irrelevant cues used in single cue training were always chicken, peach, and jam. Three young and three older participants were assigned to each cue set. In all other aspects, the stimuli and design were identical to those in Experiment 1.

Procedure—The procedure was identical to that used in Experiment 1.

Results and Discussion

Acquisition—The percentage predicted allergic reactions for the three contingencies used in compound and single cue training are shown in the top and bottom panels of Figure 2, respectively. A 2 (Age) $\times$ 6 (Block) $\times$ 3 (Contingency) mixed-factorial ANOVA for predicted allergic reactions in compound cue training revealed no effect of age on overall predictions, $F(1, 52) < 1.00$. There was a large effect of block on these predictions, $F(5, 260) = 47.43, MSE = .18, p \leq .001, \eta^2 = .48$, which did not differ for young and older adults, $F(5, 260) = 1.38, p = .23, \eta^2 = .03$. Predicted reactions were higher for the revaluation and control contingencies than for the filler contingency, $F(2, 104) = 454.90, MSE = .21, p \leq .001, \eta^2 = .90$, and this effect varied with age, $F(2, 104) = 5.27, p = .007, \eta^2 = .09$. Simple effects analyses of age for each contingency indicated that this interaction occurred because young adults' ratings for the filler contingency were lower, and thus more accurate, than those of older adults, $F(1, 52) = 7.44, MSE = .02, p = .01, \eta^2 = .09$, whereas ratings for the two groups did not differ for the revaluation, $F(1, 52) = 2.91, MSE = .01, p = .09, \eta^2 = .05$, and control, $F(1, 52) < 1.00$, contingencies. Finally, predicted reactions for the three contingencies diverged over blocks, $F(10, 520) = 62.53, MSE = .03, p \leq .001, \eta^2 = .58$, and this effect did not vary with age, $F(10, 520) = 1.28, p = .08, \eta^2 = .03$.

A 2 (Age) $\times$ 3 (Block) $\times$ 3 (Contingency) mixed factorial ANOVA for predictions in single cue training revealed no effect of age, $F(1, 52) < 1.00$, or block, $F(2, 104) = 1.13, MSE = .05, p = .33, \eta^2 = .02$, on overall predictions nor was there an interaction between these two variables, $F(2, 104) < 1.00$. Participants predicted a greater percentage of allergic reactions for the filler and irrelevant contingencies than for the revaluation contingency, $F(2, 104) = 215.91, MSE = .08, p < .001, \eta^2 = .81$, and this effect did not vary with age, $F(2, 104) = 2.69, p = .07, \eta^2 = .05$. Predictions for the three contingencies diverged over blocks, $F(4, 208) = 104.96, MSE = .04, p < .001, \eta^2 = .67$, and this effect varied for young and older

adults, $F(4, 208) = 3.02, p = .02, \eta^2 = .67$]. Analyses of the simple interaction effect of age and block for each contingency indicated that this was due to a sharper drop over blocks in predicted allergic reactions for the revaluation contingency for young adults than for older adults, $F(2, 104) = 4.24, MSE = .05, p < .02, \eta^2 = .07$, combined with the absence of any age differences in predictions over blocks for the filler, $F(2, 104) < 1.00$, and irrelevant contingencies, $F(2, 104) < 1.00$.

Compared to young adults, older adults did not achieve the same overall level of prediction accuracy during compound cue training for the filler contingency. However, they reached the same level of accuracy for the revaluation and control contingencies and their predictions for the three contingencies diverged in the same way. During single cue training, older adults learned the revaluation contingency somewhat more slowly than young adults, but they ultimately reached the same level of prediction accuracy for this contingency. Moreover, there were no age differences for the filler and irrelevant contingencies. Thus, although there were age differences in acquisition performance, they were relatively minor and older adults clearly learned to discriminate the causal contingencies.

Target Cue Ratings—Mean baseline and test ratings for target cues from the revaluation and control contingencies in this experiment are shown in Table 3. A preliminary 2 (Age) $\times$ 2 (Time) $\times$ 2 (Contingency) mixed factorial ANOVA for baseline and test ratings for revaluation and control target cues indicated that differences in these ratings once again varied by the combined effects of time of collection and age [Age $\times$ Time $\times$ Contingency, $F(1, 52) = 13.97, MSE = .98, p = .001, \eta^2 = .21$]. A subsequent 2 (Age) $\times$ 2 (Contingency) mixed-factorial ANOVA for the baseline ratings revealed no initial biases in ratings for revaluation and control target cues for either age group [Age, $F(1, 52) = 2.57, MSE = 1.91, p = .12, \eta^2 = .08$, Contingency, $F(1, 52) < 1.00$; Age $\times$ Contingency, $F(1, 52) < 1.00$]. However, the same analysis for the test ratings revealed main effects of age, $F(1, 52) = 11.03, MSE = 5.45, p = .002, \eta^2 = .17$, and contingency, $F(1, 52) = 8.87, MSE = 1.40, p < .004, \eta^2 = .15$, as well as a significant age by contingency interaction, $F(1, 52) = 16.45, p \leq .001, \eta^2 = .24$. Analysis of the simple effect of contingency for each age group revealed that once again young adults' ratings for the absent target cues from the revaluation contingency were higher than target cues from the control contingency, $F(1, 26) = 26.52, MSE = 1.22, p \leq .001, \eta^2 = .52$, but older adults' ratings did not show this retrospective revaluation effect, $F(1, 26) < 1.00$.

Recognition Confidence Ratings—Mean recognition confidence ratings for this experiment are shown in Table 4. For both young and older adults, confidence ratings were higher for the original compound cues used in this experiment than for those used in Experiment 1. Moreover, the older adults in this experiment were now as confident as young adults that they had seen these cues, $F(1, 52) = 2.80, MSE = .55, p = .10, \eta^2 = .05$, although they were still somewhat less confident about their recognition for the novel compounds, $F(1, 52) = 6.71, MSE = 2.38, p < .01, \eta^2 = .11$. On the other hand, the older adults in this experiment were more confident that they had not seen the novel compound cues than the older adults in the first experiment, $F(1, 52) = 15.43, MSE = 4.42, p \leq .001, \eta^2 = .23$, and they were as confident about their recognition of these items as the young adults in the first experiment, $F(1, 52) < 1.00$.

Experiment 2b

Once again, young adults retrospectively updated the causal efficacy of the absent target cues, whereas older adults showed no retrospective revaluation effect. This age difference occurred despite the fact that the pre-existing within-compound associations for the food cues improved older adults' memory for the original compound cues and should likewise

have facilitated indirect activation of the absent target cues during single cue training. It is possible, however, that the differences observed in older adults' acquisition of some of the causal contingencies could be responsible for the age difference in retrospective revaluation. To rule out these differences as a potential source of older adults' failure to revalue the absent target cues in this experiment, we gave a second group of older participants an additional four blocks of compound cue training and an additional two blocks of single cue training. We expected that this manipulation would improve their cue - outcome learning, further strengthen the within-compound associations between the related foods in the compound cues, and thereby reduce age differences in retrospective revaluation. Another possibility, however, is that our older adults' surprising difficulty with retrospective revaluation is not due to age-related changes in associative processes but rather to changes in their ability to reason about the causal efficacy of absent cues. Several researchers (e.g., De Houwer, Beckers, VanDorpe, 2005; Lovibond, 2003) have suggested that when updating causal beliefs about target cues, humans may use higher-order reasoning processes that combine causal beliefs about the treatment and target cues (e.g., If Cue A and B together cause the outcome, but Cue A by itself does not cause the outcome, this implies that Cue B is the cause of the outcome). Older adults experience difficulties in a variety of reasoning tasks (e.g., Hartman, Bolton, & Fehnel, 2001; Salthouse & Prill, 1987) and it is possible that they do not make accurate causal inferences about absent target cues. To examine this possibility, we developed a descriptive scenario of a retrospective revaluation problem that required causal reasoning processes, but did not require multiple learning trials or indirect activation of absent cues.

Method

Participants—An additional group of twenty-seven older adults (15 male, 12 female) participated in this experiment. Biographical and cognitive ability data for this group of participants are shown in Table 2. Age differences in these data were similar to those observed in Experiment 2a [Education, $F(1, 52) = 9.87, p \leq .003$; Vocabulary, $F(1, 52) = 6.89, p \leq .01$, DSS, $F(1, 52) = 50.92, p \leq .001$; DSIL, $F(1, 52) = 25.29, p \leq .001$; WCST, $F(1, 52) = 21.71, p \leq .001$, Reading Span, $F(1, 52) = 1.44, p \leq .24$].

Stimuli and Design—The stimuli and design for the retrospective revaluation task were identical to those used in Experiment 2a. Three older participants were assigned to each of the nine sets of related compound food cues. These participants also received a descriptive scenario of a retrospective revaluation problem that involved testing the effectiveness of two experimental fertilizer components on the blooming of a fictional plant (see Appendix B).

Procedure—The procedure was identical to that used in Experiment 1 and 2a except that participants received 10 blocks of compound cue training and five blocks of single cue training in the retrospective revaluation task and after completing this task, they were given the descriptive retrospective revaluation scenario.

Results and Discussion

Acquisition—Comparison of predicted allergic reactions for the last block of compound cue training for young adults in Experiment 2a (Block 6) and older adults in this experiment (Block 10) indicated that participants predicted more allergic reactions for the revaluation (Young, $M = 1.00, SE = .00$; Older, $M = .96, SE = .02$) and control contingencies (Young, $M = .98, SE = .02$; Older, $M = .98, SE = .02$) than for the filler contingency (Young, $M = .00, SE = .00$; Older, $M = .05, SE = .03$) and this difference did not vary with age [Age, $F(1, 52) < 1.00$; Contingency, $F(2, 104) = 1521.14, MSE = .01, p \leq .001, \eta^2 = .97$; Age $\times$ Contingency, $F(2, 104) = 2.33, p = .10, \eta^2 = .04$]. Likewise, no age differences were observed in predictions for the last block of single cue training [Age, $F(1, 52) < 1.00$;

Contingency, $F(2, 104) = 604.05$, $MSE = .02$, $p \leq .001$, $\eta^2 = .92$; Age $\times$ Contingency, $F(2, 104) < 1.00$]. For both age groups, predictions were higher for the irrelevant contingency (Young, $M = .98$, $SE = .02$; Older, $M = .95$, $SD = .02$) than for the revaluation (Young, $M = .15$, $SE = .04$; Older, $M = .15$, $SE = .04$) and filler contingencies (Young, $M = .00$, $SE = .00$; Older, $M = .00$, $SE = .00$). Thus, adding the additional compound and single cue training blocks accomplished the goal of eliminating any age differences in discrimination of the causal contingencies.

Target Cue Ratings—Mean baseline and test ratings for target cues from the revaluation and control contingencies are shown in Table 3 for the older adults tested in this experiment. As before, a preliminary 2 (Age) $\times$ 2 (Time) $\times$ 2 (Contingency) mixed factorial ANOVA indicated that the difference between revaluation and control target cues was influenced by the combination of the time at which the ratings were collected and age [Age $\times$ Time $\times$ Contingency, $F(1, 52) = 7.11$, $MSE = .95$, $p = .01$, $\eta^2 = .12$]. The subsequent 2 (Age) $\times$ 2 (Contingency) mixed factorial ANOVA for baseline ratings showed that older adults' overall ratings were higher than those of young adults, $F(1, 52) = 6.52$, $MSE = 2.61$, $p = .01$, $\eta^2 = .11$, but there was no initial bias for the target cues in the revaluation and control contingencies for either age group [Contingency, $F(1, 52) < 1.00$; Age $\times$ Contingency, $F(1, 52) < 1.00$]. A similar analysis for the test ratings revealed that young adults' overall ratings were higher than those of older adults, $F(1, 52) = 6.16$, $MSE = 6.41$, $p = .02$, $\eta^2 = .11$, ratings for target cues from the revaluation contingency were higher than those for the control contingency, $F(1, 52) = 14.17$, $MSE = 1.81$, $p \leq .001$, $\eta^2 = .21$, and this effect of contingency was again greater for young adults than for older adults, $F(1, 52) = 5.89$, $p \leq .02$, $\eta^2 = .11$. Analysis of the simple effect of contingency for each age group showed that as in the previous two experiments, young adults gave higher ratings to target cues from the revaluation contingency than the control contingency, $F(1, 26) = 28.52$, $MSE = 1.22$, $p \leq .001$, $\eta^2 = .52$, whereas older adults' ratings for these cues did not differ, $F(1, 26) < 1.00$.

Recognition Confidence Ratings—Mean recognition confidence ratings for the older adults in this experiment are shown in Table 4. Compared to the older participants in Experiment 2a, these older adults were more confident that they had seen the original compound cues, $F(1, 52) = 6.99$, $MSE = .49$, $p = .01$, $\eta^2 = .12$, and they were equally confident that they had not seen the novel compound cues, $F(1, 52) < 1.00$. Moreover, their recognition confidence ratings for both original and novel compounds were now quite close to the maximum rating. Thus, the four extra blocks of compound cue training further strengthened the pre-existing within-compound associations between the food cues.

Causal Inferences—Twenty-six of the 27 older participants in this experiment provided usable responses to the descriptive retrospective revaluation scenario. Of these, 24 responded accurately that the absent target cue caused the outcome and only two responded inaccurately that the presented treatment cue caused the outcome. Thus, older adults are able to make accurate inferences about the changed causal efficacy of absent cues when given a descriptive revaluation scenario. This finding rules out an age-related deficit in this type of reasoning as the source of their difficulty with experienced – based retrospective revaluation.

Correlational Analyses—One additional question of interest is whether variation in basic cognitive functioning or recognition accuracy might be related to older adults' retrospective revaluation performance. We therefore combined our older adults' data from Experiments 1, 2a, and 2b to increase power and conducted analyses of first-order correlations between these variables. To measure cognitive functioning, we used each participant's performance on tests of processing speed (DSS), incidental associative learning (DSIL), working memory

(Reading Span), semantic memory (Mill Hill Vocabulary), and category learning (WCST), and to measure recognition accuracy, we added the absolute value of the participant's recognition confidence ratings for original and novel food pairs (higher = more accurate). Variables that are important for retrospective revaluation of absent cues should be related to ratings for target cues from the revaluation contingency. This analysis revealed that older participants who had higher scores for incidental associative learning, working memory, and recognition accuracy also had higher causal efficacy ratings for the target revaluation cues [Incidental Associative Learning, $r = .31$, $t(79) = 2.88$, $p = .005$; Working Memory, $r = .22$, $t(79) = 2.02$, $p = .05$; Recognition Accuracy, $r = .24$, $t(79) = 2.18$, $p = .03$]. No other measure was related to these ratings and none of the measures of cognitive functioning and recognition accuracy were related to ratings for the target control cues [All correlations, $-.002 \leq r \leq .18$].

Experiment 3

In the previous two experiments, older adults did not show retrospective revaluation of the absent target cues even though they had little difficulty learning the original compound and single cue – outcome relationships and reasoning accurately about the changed causal efficacy of absent cues. In Experiment 1, this could be attributed to their weaker within-compound associations for unrelated treatment and target food cues; however, in Experiment 2, they received additional compound cue training for food cues with pre-existing within-compound associations and their memory for these associations was quite accurate. This pattern of findings suggests that even though older adults had the requisite within-compound associations, they did not activate the representations of absent target cues in a way that allowed them to revalue the causal efficacy of these cues. In Experiment 3, we tested this activation hypothesis by presenting small, grey icons of the target cues that were originally paired with the treatment cues in the corner of the monitor screen during single cue training. If age-related changes in associative activation contribute to older adults' difficulty with retrospective revaluation, eliminating the need for this process during the single cue learning trials may reduce age differences in this causal learning task.

Method

Participants—Twenty-seven young participants (8 male, 19 female) and twenty-seven older participants (10 male, 17 female) participated in this experiment. Biographical and cognitive ability data for these groups are shown in Table 2. Age differences in these data were again similar to those in the previous two experiments [Education, $F(1, 52) = 4.12$, $p \leq .05$; Vocabulary, $F(1, 52) = 52.89$, $p \leq .001$, DSS, $F(1, 52) = 23.75$, $p \leq .001$; DSIL, $F(1, 52) = 13.03$, $p \leq .001$; WCST, $F(1, 52) = 3.22$, $p \leq .08$; Reading Span, $F(1, 52) < 1.00$].

Stimuli and Design—The retrospective revaluation design was identical to that used in the two previous experiments and the compound cues were the unrelated food pairs used in Experiment 1. However, the single food cues created for Experiment 1 were modified by inserting a 2.28" × 2.28" grey image of the foods they were paired with during compound cue training in the upper right corner of the PowerPoint slide prior to saving the slide as a QuickDraw picture. Because the irrelevant cues were presented only during single cue training, the modified pictures of these cues included the grey image of one of the other two irrelevant cues.

Procedure—The procedure was identical to that used in Experiment 2 except that the acquisition instructions were altered to account for the small grey picture of food shown with the colored food cue during single cue training. The altered instructions are shown in Appendix A.

Results and Discussion

Acquisition—Comparison of young and older adults' predictions for the last block of compound cue training revealed that participants predicted more allergic reactions for the revaluation (Young, $M = .96$, $SE = .02$; Older, $M = .95$, $SE = .04$) and control contingencies (Young, $M = .99$, $SE = .01$; Older, $M = .96$, $SE = .03$) than for the filler contingency (Young, $M = .01$, $SE = .01$; Older, $M = .04$, $SE = .02$) and this difference did not vary with age [Age, $F(1, 52) < 1.00$; Contingency, $F(2, 104) = 1334.13$, $MSE = .01$, $p \leq .001$, $\eta^2 = .96$; Age $\times$ Contingency, $F(2, 104) < 1.00$]. Likewise, no age differences were observed in predictions for the last block of single cue training [Age, $F(1, 52) < 1.00$; Contingency, $F(2, 104) = 303.01$, $MSE = .04$, $p \leq .001$, $\eta^2 = .85$; Age $\times$ Contingency, $F(2, 104) < 1.00$]. For both age groups, predictions were higher for the irrelevant contingency (Young, $M = .91$, $SE = .04$; Older, $M = .89$, $SE = .04$) than for the revaluation (Young, $M = .11$, $SE = .04$; Older, $M = .13$, $SE = .05$) and filler contingencies (Young, $M = .01$, $SE = .01$; Older, $M = .01$, $SE = .01$). Thus, all participants learned to discriminate the causal contingencies.

Target Cue Ratings—Mean target cue baseline and test ratings for the young and older adults tested in this experiment are shown in Table 3. A preliminary 2 (Age) $\times$ 2 (Time) $\times$ 2 (Contingency) mixed factorial ANOVA indicated that the difference between revaluation and control target cue ratings varied according to whether these ratings were collected at baseline or test, but this effect did not vary by age [Time $\times$ Contingency, $F(1, 52) = 11.39$, $MSE = 1.67$, $p = .001$, $\eta^2 = .18$; Age $\times$ Time $\times$ Contingency, $F(1, 52) < 1.00$]. However, to facilitate comparison of the present results with those of the previous experiments, we again conducted separate 2 (Age) $\times$ 2 (Contingency) mixed factorial ANOVAs for the baseline and test ratings. Analysis of the baseline ratings revealed no differences for target cues used in the revaluation and control contingencies for either group [Age, $F(1, 52) = 2.13$, $MSE = 3.49$, $p = .15$, $\eta^2 = .04$; Contingency, $F(1, 52) = 2.71$, $MSE = .24$, $p = .11$, $\eta^2 = .05$; Age $\times$ Contingency, $F(1, 52) < 1.00$]. Analysis of the test ratings indicated that overall ratings were higher for young than older adults, $F(1, 52) = 339.62$, $MSE = 6.43$, $p = .02$, $\eta^2 = .11$, and ratings were higher for cues in the revaluation contingency than for those in the control contingency, $F(1, 52) = 17.06$, $MSE = 2.84$, $p \leq .001$, $\eta^2 = .25$. Now, however, both young and older adults showed this retrospective revaluation effect [Age $\times$ Contingency, $F(1, 52) < 1.00$, $\eta^2 = .002$]. Thus, the presence of the small icon of the target cue during single cue training eliminated the age difference in retrospective revaluation that was observed in the previous two experiments.

Recognition Confidence Ratings—Mean recognition confidence ratings for this experiment are shown in Table 4. Not surprisingly, using compound cues with unrelated foods reduced both young and older adults' recognition confidence ratings relative to those of participants in Experiment 2. However, the memory performance of the older adults in this experiment was somewhat better than the performance of those in Experiment 1. Specifically, in contrast to the older adults in Experiment 1, the older adults in this experiment were as confident as young adults that they had seen the original compound cues, $F(1, 52) < 1.00$, but like the older adults in Experiment 1, they were less confident that they had not seen the novel compound cues, $F(1, 52) = 11.77$, $MSE = 2.50$, $p = .001$, $\eta^2 = .18$. Thus, providing the icon of the absent cue during single cue training provided a benefit in older adults memory for the original food pairs, but did not completely eliminate age differences in recognition accuracy and confidence.

General Discussion

In this study, we used a two-stage, recovery from overshadowing design to examine age-related changes in the ability to retrospectively revalue the causal efficacy of absent cues. In

Experiment 1, we used unrelated food pairs to generate the compound and single cues for acquisition training. Although participants in the two age groups learned the causal contingencies for these cues equally well, unlike young adults, older adults did not revalue the causal effectiveness of the absent food cues and their memory for the compound food cues was poor. In Experiments 2a and 2b, we used food pairs with pre-existing associations and gave older adults additional acquisition trials. We also examined whether they were able to reason accurately about the changed causal efficacy of absent cues when given a descriptive causal scenario. Despite having better memory for the food pairs, more trials in which to accomplish cue – outcome learning and revaluation, and accurate reasoning processes, older adults again did not revalue the absent cues. In Experiment 3, we again used unrelated food pairs, but during single cue training, we presented unobtrusive icons of the food cues that were previously absent. This time, older adults revalued the causal efficacy of these cues. Together, these findings suggest that age-related changes in basic cue – outcome associative learning are relatively small and further, that older adults can learn and update the causal efficacy of at least two causal cues as long as these stimuli are physically present. However, there is a substantial age – related decline in the formation of within – compound or cue – cue associations and in the use of these associations to indirectly activate representations of absent causal cues.

The findings from this study are consistent with prior research showing that within - compound associations are important in retrospective revaluation (Aitken et al., 2001; Chapman, 1991; Dickinson & Burke, 1996; Larkin et al., 1998; Mitchell et al., 2005; Wasserman & Berglan, 1998). Older adults showed reduced accuracy and confidence in their memory for within – compound associations generated from *unrelated* food cues suggesting that they formed relatively weak associations between these cues. This very likely contributed to their failure to show any retrospective revaluation for the absent target cues. Thus, age can be added to the list of variables leading to weak within - compound associations and reduced retrospective revaluation. However, an age – related decline in the ability to acquire within-compound associations does not provide a complete account of the striking difference in our young and older adults' retrospective revaluation performance. Our older adults' accuracy and confidence in their memory for within – compound associations generated from *related* food cues was quite high but they nonetheless failed to show any retrospective revaluation. This suggests that even when older adults have pre-existing within – compound associations, they do not use these associations to activate the representations of the absent cues.

Our older adults' inability to form strong within – compound associations and use pre – existing associations to activate absent cue representations provides further evidence of an age – related associative deficit that affects older adults' ability to bind events into complex memories that can be retrieved by appropriate cues (e.g., Olds & Naveh – Benjamin, 2008). According to Johnson and Chalfonte (1996), binding temporally contiguous stimuli during encoding increases the future capacity of each stimulus to non-strategically reactivate the representations of the others. Subsequently, this reactivation process serves to both strengthen existing associations and facilitate associative binding for stimuli that are “temporally, spatially, or cognitively discontinuous” (p. 319). Age – related disruptions in binding and/or reactivation are thought to be responsible for impairments in older adults' memory for item – item, item – context, and item – feature relations (e.g., Chalfonte & Johnson, 1996; Kliegl & Lindenberger, 1993; Hashtroudi, Johnson, & Chrosniak, 1989; for a review see Spencer & Raz, 1995).

By this analysis, the impairments seen in older adults' causal learning for absent cues (Mutter, et al., 2006; Mutter & Pliske, 1996; Mutter & Plumlee, 2009; Mutter, et al., 2009; Mutter & Williams, 2004) are due largely to ineffective binding and reactivation processes

for cue – cue and context – cue associations. In retrospective revaluation, older adults form weak associations between the temporally contiguous unrelated food cues during compound cue training because they have difficulty binding these cues and/or using reactivation processes to further strengthen the cue – cue associations. Likewise, they do not adjust the causal efficacy of the absent target cues from related food compounds because they are less able to reactivate the representations of these cues via pre-existing associations. Some additional evidence for the importance of these associative processes in causal learning comes from the finding that although older adults as a group showed no retrospective revaluation in Experiments 1, 2a and 2b, greater recognition accuracy for the compound food cues and better retrieval of associations acquired incidentally in a different task were associated with higher causal efficacy ratings for the absent target cues. Finally, when reactivation processes were not required (i.e., for the physically present treatment cues and for the target cues whose icons were presented in Experiment 3), older adults had no difficulty revaluing causal efficacy.

A similar explanation may apply to the age differences observed in preventative causal learning (e.g., Mutter et al., 2006; Mutter & Pliske, 1996; Mutter & Plumlee, 2009; Mutter et al., 2009; Mutter & Williams, 2004). In this case, older adults are less able to bind and strengthen associations between causal cues and the context and to reactivate the representations of absent cues via these contextual associations. As a result, they are less likely to learn the preventative causal efficacy of these cues. We should also note, however, that while our findings offer considerable support for the idea that age – related changes in associative binding and reactivation processes are directly responsible for the decline in older adults' causal learning, it is also possible that activating absent cue representations while simultaneously learning or revaluing the causal efficacy of these cues exceeds older adults' working memory resources. The relatively small relationship between working memory span and causal efficacy ratings for the revaluation cues does not offer strong support for this idea, but at this point we cannot rule it out.

The findings from this study raise another interesting question; namely, why doesn't the associative deficit that apparently has such a detrimental effect on older adults' ability to acquire and use cue – cue and context – cue associations have the same impact on their ability to acquire generative cue – outcome associations either in this study or in prior research on contingency and causal learning (e.g., Mutter et al., 2006; Mutter & Pliske, 1996; Mutter & Plumlee, 2009; Mutter et al., 2009; Mutter & Williams, 2004; Parr & Mercier, 1998). We have no definitive answer to this question, but the source of the difference may lie in the compensatory effect of error – driven learning processes on the acquisition of these associations.

Error - driven learning has been linked to phasic responses of the dopamine neurons in the ventral striatum to the occurrence of surprising or altered reward – related outcomes. These responses are thought to be responsible for the generation of positive and negative prediction error signals that modulate the formation of associations between cues and outcomes (Corlett et al., 2004; Schultz, 2007; Waelti et al, 2001). This view is consistent with Rescorla and Wagner's (1972) associative learning theory and suggests that a positive prediction error signal generated upon the presentation of an unexpected outcome strengthens these associations while a negative prediction error signal generated upon omission of an expected outcome weakens them (e.g., den Ouden, Friston, Daw, McIntosh, & Stephen, 2009). Further evidence for this view comes from findings showing that the level of activation in the ventral striatum and prefrontal cortex is correlated with the degree of causal learning (Corlett et al., 2004; Turner et al, 2004). Research also shows that error – driven processes can modulate hippocampally - mediated associative binding and reactivation (for a review, see Shohamy & Adcock, 2010). For example, reward – predicting

stimuli produce better recollection and source memory than stimuli predicting no or low rewards and greater activity in the hippocampus and midbrain during encoding of these stimuli is associated with better memory (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006; Wittmann, Schott, Guderian, Frey, Heinze, & Düzel, 2005).

During retrospective revaluation and other causal learning tasks, the goal of reducing errors in outcome prediction engages error - driven learning (Cortlett et al., 2004; Turner et al., 2004). This may compensate for age - related inefficiencies in hippocampally - mediated associative binding and reactivation (e.g., Bunzeck, et al., 2007; Daselaar, Fleck, Dobbins, Madden, & Cabeza, 2006; Driscoll et al., 2003; Mitchell, Johnson, Raye, & Esposito, 2000) and thereby strengthen older adults' generative cue - outcome associations. This compensatory effect would not be as likely to occur for cue - cue or context - cue associations in causal learning tasks because there is no overt reward for learning these associations and unexpected combinations of these stimuli rarely occur. As a result, it is less likely that error - driven learning would be elicited to modulate older adults' associative binding and reactivation for cue - cue or context - cue pairs. Structuring task requirements to elicit this type of learning might have a beneficial effect on older adults' acquisition of these associations.

In conclusion, the pervasive age -related deficits seen in retrospective revaluation and preventative causal learning are apparently due to a decline in older adults' ability to bind predictive cues with other discrete cues or with the context and to reactivate the representations of absent cues via these associations. These changes in older adults' causal learning are thus examples of the more fundamental age - related associative deficit that has been observed in prior studies of older adults' memory for item - item, item - context, and item - feature associations (e.g., Chalfonte & Johnson, 1996; Hashtroudi, Johnson, & Chrosniak, 1989; Olds & Naveh - Benjamin, 2008; Spencer & Raz, 1995). Older adults are more successful at acquiring cue - outcome associations in generative causal learning and this may be due to the compensatory effect of error - driven processes during the acquisition of these associations. Additional research is needed to determine whether inducing these processes during the acquisition of cue - cue and context - cue associations could provide similar benefits for older adults.

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Appendix A: Instructions for the Retrospective Revaluation Tasks used in Experiments 1 - 3

Baseline Rating of Causal Efficacy

This is an exercise on how people form opinions. The instructions for the exercise will appear on the computer screen and you will make your responses by pressing keys on the computer keyboard. In the first part of the exercise, we would like to get your initial opinions about some foods. Imagine that an ordinary individual who is completely unknown to you has eaten certain foods. We would like you to rate the likelihood that this individual will have an allergic reaction after eating each of those foods. You will see a separate screen for each food that this individual has eaten. After each is displayed, refer to the opinion scale at the bottom of the screen and type in the number that corresponds to your opinion of the likelihood that the individual would have an allergic reaction to this food. There are two

facts that you should remember as you complete this exercise: 1. You should base your opinions on the fact that most people do not suffer from food allergies. 2. You have no reason to believe that this individual is any different than most people.

Compound Cue Training

For this part of the exercise, we would like you to imagine that you are an allergist. That is, you are someone who tries to discover the cause of allergic reactions in people. You have just been presented with a new patient, “Mr. X” who suffers from allergic reactions following some meals but not others. In an attempt to discover what foods cause “Mr. X” to have allergic reactions, you arrange for him to eat various foods for a meal on each day, and observe whether or not he has an allergic reaction. To begin with, you will give him meals containing two foods.

Experiments 1, 2a, 2b. Then, in later days, you will give him meals containing only one food. You will see a separate screen for each day of the allergy test. On each screen, you will see a large color picture of what your patient ate for dinner that day.

Experiment 3. A large color picture of the foods that were eaten on that day will be shown centered on the screen. Then, in later days, you will give him meals containing only one food. As before, a large color picture of the food that was eaten that day will be shown in the center of the screen. However, there will also be a small picture of food shown in grey at the top right of the screen. This food was not eaten on this day of the allergy test, but may have been eaten previously with the food in the large color picture.

Please study the foods carefully and remember that your task as an allergist is to determine which food or foods are causing allergic reactions. After seeing each day’s meal, you will be asked to predict whether or not the meal caused an allergic reaction in your patient. You simply press the key on the keyboard marked “Y” (for Yes) if you think that your patient will suffer an allergic reaction and press the key marked “N” (for No) if you think that your patient will not suffer an allergic reaction. Speed of response is not important, so take as much time as you need before responding. After you make your prediction, the computer will tell you whether or not the patient actually suffered from a reaction. Obviously, at first you will have to guess since you will not know anything about your patient, but hopefully you will begin to learn which foods cause an allergic reaction. You might view this exercise as a game and try to make as many correct predictions as you can. Later in the exercise, you will again be asked to rate the foods you previously rated, but when doing these ratings, you will rate the likelihood that each food would cause your patient, “Mr. X”, to have an allergic reaction. So for these ratings, you will use all of the knowledge you have acquired during your patients’ daily allergy tests.

Test Rating of Causal Efficacy

You will now see a series of foods and an opinion scale identical to the one you saw before. We would like you to rate the likelihood of an allergic reaction to the food for your patient, “Mr. X”. When you make your ratings this time, please consider all of the information you have acquired during your patient’s daily allergy tests.

Recognition Confidence Rating

You will now be presented with another selection of meals, all of which are comprised of two foods. You must try and decide if these meals are ones that you have seen already, i.e., foods that were previously given together as meals to your patient. As each pair of foods is displayed, using the new scale at the bottom of the screen, rate how sure you are that you

have seen that pair together before, or how sure you are that you have not seen that pair before. Speed of response is not important, so take as much time as you like to respond.

Appendix B:

Descriptive Retrospective Revaluation Scenario

Imagine that you are employed by the National Flowering Plants Laboratory (NFPL). NFPL develops experimental fertilizer components and tests how these components affect blooming in the Lanyu plant. The Lanyu, an exotic plant, is imported from Brazil. Your job is to evaluate the effectiveness of these fertilizer components. To test the components, you sometimes apply two of them to a group of plants and you sometimes apply one of them to a group of plants. The plants in each group have been planted in the same medium, they are watered at the same time daily, and all are given the same amount of water and sunlight. The results of a test of two fertilizer components are summarized below.

Test for Fertilizer Components A and B

Fertilizer components A and B were applied.

The Lanyu plants did bloom.

THEN

Fertilizer component A was applied.

The Lanyu plants did not bloom.

Please choose the best conclusion for the effectiveness of each fertilizer component by checking one of the following choices: This component causes blooming; This component neither prevents nor causes blooming; or This component prevents blooming.

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Figure 1. Percent predicted allergic reactions across compound cue and single cue training blocks for young and older adults in Experiment 1. Error bars represent standard error of the mean.

Figure 2. Percent predicted allergic reactions across compound cue and single cue training blocks for young and older adults in Experiments 2a. Error bars represent standard error of the mean.

Figure 3.

Percent predicted allergic reactions across compound cue and single cue training blocks for young and older adults in Experiment 3. Error bars represent standard error of the mean.

Table 1

Retrospective Revaluation Design used in Experiments 1 - 3

Contingency	Compound Cue Training	Single Cue Training	Test Ratings
Revaluation	AB+, CD+, EF+	A-, C-, E-	A, C, E, <i>B, D, F</i>
Control	IJ+, KL+, MN+		I, K, M, <i>J, L, N</i>
Filler	RS-, TU-, VW-	R-, T-, V-	R, T, V, S, U, W
Irrelevant		X+, Y+, Z+	X, Y, Z

Note: A plus sign (+) after a cue indicates that the cue produced an allergic reaction; a minus (-) sign indicates that the cue did not produce an allergic reaction.

Table 2

Participant Characteristics by Age Group for Experiments 1 – 3

Group	Age	Education (Yrs)	Digit Symbol (Speed)	Digit Symbol (Learning)	Reading Span	Vocabulary	WCST Categories
Experiment 1							
Young	20.15 (1.92)	13.67 (1.59)	85.11 (09.96)	22.22 (4.60)	2.59 (1.25)	31.44 (6.08)	4.41 (0.93)
Older	69.33 (5.88)	15.93 (2.35)	62.04 (10.27)	18.04 (4.42)	2.00 (0.96)	38.46 (6.74)	2.78 (1.40)
Experiment 2a							
Young	20.37 (2.40)	13.26 (1.50)	82.59 (11.91)	23.33 (4.58)	2.48 (0.89)	31.19 (5.32)	4.44 (1.01)
Older	67.74 (5.31)	14.67 (2.60)	59.07 (10.74)	16.37 (5.05)	2.04 (0.94)	37.41 (7.12)	2.74 (1.35)
Experiment 2b							
Older	67.26 (4.60)	15.11 (2.66)	54.93 (16.3)	15.70 (6.41)	2.22 (1.05)	36.70 (8.12)	2.85 (1.51)
Experiment 3							
Young	20.22 (2.36)	14.11 (1.65)	86.00 (13.42)	22.22 (4.63)	2.67 (1.07)	29.70 (3.87)	3.62 (1.30)
Older	67.48 (4.76)	15.33 (2.66)	66.85 (15.39)	17.70 (4.56)	2.41 (1.55)	41.04 (7.11)	2.89 (1.62)

Note: Standard deviations are in parentheses.

Table 3

Mean Baseline and Test Ratings by Age Group for Treatment and Control Cues in Experiments 1-3.

Group	Baseline Ratings		Test Ratings	
	Revaluation (BDF)	Control (JLN)	Revaluation (BDF)	Control (JLN)
Unrelated Food Cues (Experiment 1)				
Young	1.11 (1.15)	.96 (1.00)	4.99 (2.20)	3.75 (1.88)
Older	1.01 (0.90)	.73 (0.73)	2.86 (1.65)	3.07 (2.00)
Related Food Cues (Experiment 2a)				
Young	0.89 (0.92)	0.91 (0.89)	6.39 (1.83)	4.79 (1.42)
Older	1.40 (1.29)	1.26 (1.23)	3.98 (2.04)	4.22 (2.04)
Related Food Cues, Extra Trials (Experiment 2b)				
Older	1.69 (1.38)	1.56 (1.40)	4.56 (2.67)	4.21 (1.99)
Unrelated Food Cues, Icon of "Absent" Cue (Experiment 3)				
Young	0.89 (1.07)	0.76 (0.99)	5.91 (2.06)	4.30 (1.83)
Older	1.44 (1.55)	1.26 (1.71)	4.43 (2.32)	3.36 (2.36)

Note: Standard deviations are in parentheses.

Table 4

Mean Recognition Ratings by Age Group for Original and Novel Compound Cues in Experiments 1 - 3

Group	Original Compounds	Novel Compounds
Unrelated Food Cues (Experiment 1)		
Young	3.90 (0.81)	-3.75 (2.12)
Older	3.09 (1.67)	-1.55 (2.05)
Related Food Cues (Experiment 2a)		
Young	4.62 (0.59)	-4.88 (0.33)
Older	4.28 (0.86)	-3.80 (2.16)
Related Food Cues, Extra Trials (Experiment 2b)		
Older	4.78 (0.47)	-4.21 (1.36)
Unrelated Food Cues, Icon Reminder (Experiment 3)		
Young	4.10 (1.24)	-4.22 (0.99)
Older	3.93 (0.98)	-2.74 (2.01)

Note: Standard deviations are in parentheses.