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The Role of Contingency and Contiguity in Young and Older Adults' Causal Learning

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Contingency and temporal contiguity are important "cues to causality." In this study, we examined how aging influences the use of this information in response–outcome causal learning. Young and older adults judged a generative causal contingency (i.e., outcome is more likely when a response is made) to be stronger when response and outcome were contiguous than when the outcome was delayed. Contiguity had a similar beneficial effect on young adults' preventative causal learning (i.e., outcome is less likely when a response is made). However, older adults did not judge the preventative relationship to be stronger when the response and outcome were separated by a short delay or when the outcome immediately followed their response. These findings point to a fundamental age-related decline in the acquisition of preventative causal contingencies that may be due to changes in the utilization of cues for the retrieval of absent events.

Key Words: Associative processes—Causal learning—Cue utilization—Temporal context.

THE contemporary study of causal learning owes much of its impetus to the work of David Hume (1739/1969), who argued that causality cannot be directly perceived but must be inferred from observable cues in the environment. According to Hume, the detection of a causal relationship between two events will be more likely if the events reliably and consistently co-occur and if one event follows the other closely in time. In support of this view, research has shown that contingency and temporal contiguity, respectively, are two of the most important "cues to causality" (e.g., Buehner, 2005; Shanks & Dickinson, 1991; Shanks, Pearson, & Dickinson, 1989). Studies have consistently revealed an age-related decline in sensitivity to causal contingency (e.g., Mutter, Haggbloom, Plumlee, & Schirmer, 2006; Mutter, Strain, & Plumlee, 2007; Mutter & Williams, 2004), but there has been little research on the impact of temporal contiguity in older adults' causal learning. We therefore varied the contingency and temporal contiguity between a self-generated response and an outcome to further examine how aging influences the use of these cues to causality.

Much research on human causal learning has focused on how causal judgments change in response to variations in contingency. Typically, participants receive problems in which they are asked to discover the effect of pressing a response key (R) on the illumination of a triangle (O). The R–O contingency, which varies by problem, is defined statistically in terms of RO—the difference between the conditional probability of the outcome in the presence of the response [P(O/R)] and the conditional probability of the outcome in the absence of the response [P(O/~R)]. These conditional probabilities are computed from the frequencies of occurrence within a problem of the response–outcome event state combinations in the 2×2 contingency table (see Figure 1). In a generative or positive contingency, P(O/R) is greater than P(O/~R), so the outcome is more likely to occur when the key is pressed, whereas in a preventative or negative contingency, P(O/~R) is greater than P(O/R), so the outcome is more likely to occur when the key is not pressed. In noncontingent relationships, these two conditional probabilities are equal and the response has no impact on the occurrence of the outcome.

Young adults are remarkably accurate at discriminating causal contingency (e.g., Chatlosh, Neunaber, & Wasserman, 1985; Dickinson, Shanks, & Evenden, 1984; Shanks, 1987; Wasserman, Chatlosh, & Neunaber, 1983; Wasserman, Elek, Chatlosh, & Baker, 1993). However, their ability to discriminate causal contingency declines as the interval between a causal cue and outcome increases. When an outcome is delayed by 2 s, young adults' causal ratings for generative relationships are significantly lower than the actual contingency, and when the outcome is delayed by as much as 4 s, they rate the events as noncontingent (e.g., Shanks & Dickinson, 1991; Shanks et al., 1989). Likewise, when young adults are asked to identify the strongest generative cause of an outcome, they are more likely to select a high-contingency cue over a low-contingency cue, but only when the high-contingency cue is separated from the outcome by no more than 2.5 s (Buehner & McGregor, 2005).

Associative models have been particularly successful at describing the role of contingency in causal learning. The most influential of these, the Rescorla–Wagner model (R-W; Rescorla & Wagner, 1972), proposes that cues that are physically present in the learning environment (e.g., the response and the background or context) compete for the limited amount of associative (i.e., predictive) strength supported by an outcome. The associative strength of each of these cues increases when it is followed by an *unexpected outcome* and decreases when it is not followed by an *expected*

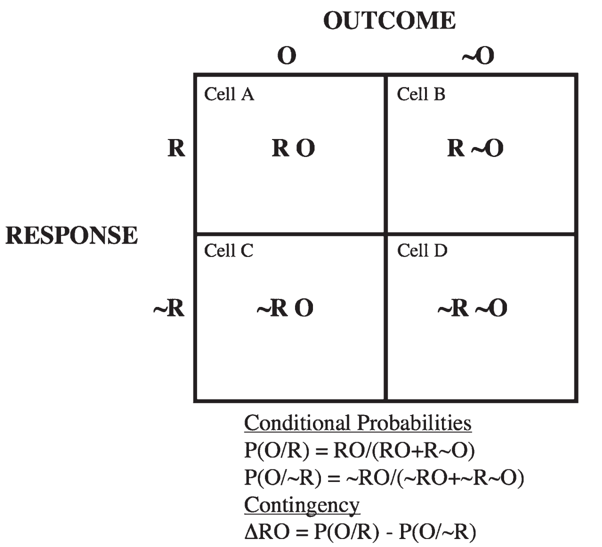

Figure 1. A 2 × 2 contingency table. The variables in the cells of the contingency table represent the frequencies of co-occurrence for the two states of a candidate cause and outcome.

outcome. However, the nonoccurrence of an event can also serve as an important causal cue. In Van Hamme and Wasserman's (1994) modification of the R-W model, a causal cue that has occurred before in the learning environment but is now missing may be retrieved and encoded as absent. The associative strength of this absent but *expected cue* decreases when the outcome occurs and increases when the outcome does not occur. This allows learning trials representing all four event combinations in the contingency table to contribute to the associative value of a target causal cue. For generative causal contingencies, the outcome frequently follows a presented cue (e.g., the key press), and its aggregate associative value will be excitatory; for preventative contingencies, the outcome frequently occurs in the absence of the expected cue (e.g., no key press) and its aggregate associative value will be inhibitory.

In the R-W model (Rescorla & Wagner, 1972), temporal contiguity is necessary, but the contingency between a causal cue and the outcome determines the cue's predictive strength. In Wagner's (1981) SOP model (*s*tandard *o*perating *p*rocedures of memory) and Dickinson's mSOP model (*m*odified SOP; Aitken & Dickinson, 2005; Dickinson & Burke, 1996), the temporal overlap of cue and outcome activation states in working memory is a central aspect of associative learning. Focal attention to events that are physically present induces a high state of activation (A1) for their representations. Without rehearsal, this activation decays to a lower state (A2) and eventually returns to the inactive state (I). The representations of absent but expected events are activated directly into the A2 state via associative retrieval processes. Excitatory associations are formed between cue and outcome representations that are simultaneously in the same state of activation (i.e., A1–A1 or A2–A2), inhibitory associations are formed between those in different states of activation (i.e., A1–A2 or A2–A1), and no associations are formed between representations in the inactive state (i.e., I–A1, I–A2, A1–I, A2–I, I–I). When an outcome is delayed, the representation of the target cause may have decayed to the A2 or I state. Weak temporal contiguity will therefore reduce the perceived causal effectiveness of a causal cue even if there is a strong contingency between this cue and the outcome. This idea is clearly supported by research on young adults' generative causal learning (e.g., Shanks & Dickinson, 1991; Shanks et al., 1989), although it has not been tested with preventative causal learning.

Studies have shown that older adults detect differences in causal contingency, although compared with young adults their contingency discrimination is less accurate, especially for preventative contingencies (e.g., Mutter & Williams, 2004; Mutter et al., 2006, 2007). However, there is little information on the role that temporal contiguity plays in older adults' causal learning. Mutter and Williams addressed this issue indirectly using an operant version of the R–O causal learning task (cf. Hammond, 1980; Chatlosh et al., 1985). Causal contingency varied over a series of problems, and contingency discrimination was examined after a maximum 1-s or 4-s R–O sampling interval. Older adults were sensitive to differences in causal contingency, but their performance was unaffected by the length of the sampling interval, whereas young adults' performance was substantially better with the short sampling interval (cf. Shanks et al., 1989). These findings suggest that older adults did not respond to temporal contiguity in the same way as young adults; however, as Mutter and Williams noted, this may have been an artifact of the operant procedure used in the task.

Operant tasks provide relatively little experimental control over the actual contiguity between response and outcome events. On each learning trial, the outcome is programmed to occur (or not occur) at the end of a fixed sampling interval, but the participant is free to make the response that triggers this event anywhere within that interval. Contiguity is weaker on average in a problem with 4-s sampling intervals than in one with 1-s intervals, but the actual contiguity between the response and outcome varies over trials. Moreover, although problems are divided into sampling intervals, from the participants' point of view the event stream is continuous. This increases the difficulty of parsing the event stream into response-outcome pairs (e.g., Buehner, 2005). Finally, there are no constraints on the number of responses that participants can make during the sampling interval, and Mutter and Williams' (2004) participants had relatively high rates of responding during the longer interval. Most of these responses were not followed by the outcome, which likely served to decrease the actual P(O/R).

The current experiment was conducted to obtain a clearer picture of the impact of aging on the use of contingency and contiguity cues in causal learning. Young and older participants were again given R–O causal learning problems in which pressing a key was a generative cause,

Table 1. Participant Characteristics

	Young (Experiment 1)		Older (Experiment 1)		Older (Experiment 2)
	OD-1000	OD-4000	OD-1000	OD-4000	OD-50
N	24	24	24	24	12
Age (y)	20.21 (2.04)	19.50 (1.61)	70.33 (7.04)	70.83 (7.98)	67.42 (5.78)
Education (y)	13.63 (1.58)	12.90 (1.40)	14.88 (2.64)	14.15 (3.03)	12.91 (1.70)
Processing speed					
Pattern comparison*	57.04 (9.64)	58.50 (9.24)	41.79 (9.58)	42.21 (9.69)	43.00 (4.45)
Digit symbol*	82.67 (12.20)	85.54 (16.24)	59.25 (14.29)	59.00 (13.98)	60.08 (13.09)
Working memory executive function					
Reading span*	2.92 (1.50)	2.58 (0.93)	1.91 (1.01)	1.87 (1.03)	1.92 (0.67)
Verbal knowledge					
Vocabulary*	29.96 (5.19)	30.09 (4.09)	39.25 (7.98)	39.92 (9.47)	35.17 (5.04)
Conditional associative learning					
Proportion forgotten*	.10 (.13)	.16 (.20)	.32 (.23)	.30 (.21)	.46 (.26)

Notes: Table entries are means with standard deviation in parentheses. OD = outcome delay. Pattern comparison (Salthouse, 1994), Wechsler Adult Intelligence Scale-III digit symbol (Wechsler, 1997), reading span (Salthouse & Babcock, 1991), Mill Hill Vocabulary (Raven, Raven, & Court, 1989), and conditional associative learning (e.g., Levine, Stuss, & Milberg, 1997).

*Age, $p \leq .05$.

a preventative cause, or noncontingent with the outcome. The beginning of each trial was clearly delineated, participants were given either 750 or 2,500 ms to prepare their response, with a countdown timer to mark the interval, and they were allowed to respond only once during this interval. Because the consequences of both executing and withholding the key press are important in contingency discrimination, the R–O temporal relationship was fixed relative to each of these choices. Specifically, a key press initiated either a 1-s or a 4-s clock, and the outcome occurred at the end of this delay period according to the programmed P(O/R). If no key press was made, the outcome occurred at the end of the marked RPI according to the programmed P(O/~R). Both young and older adults tended to key-press about midway through the response preparation interval [RPI] and they may also have made their choice to not key-press around the same time. When participants made no key press, outcome occurrence was keyed to the end of the RPI, so there may have been an unavoidable extra delay between their response choice and the outcome. The countdown timer served to bridge the gap between a choice to not key-press and the end of the RPI and should therefore mitigate the effect of this extra delay [e.g., Reed, 1999].

Both young and older adults should be able to distinguish between contingent and noncontingent R–O relationships, but older adults may again be less accurate than young adults at discriminating these contingencies (cf. Mutter & Williams, 2004; Mutter et al., 2006, 2007). However, like young adults, they should benefit from stronger temporal contiguity. Older adults' contingency discrimination may also improve if they are given more time to prepare their response. Although no causal learning studies have directly addressed this issue, there is evidence that an age-related decline in processing speed (e.g., Salthouse, 1996) may lead to greater impairments in older adults' contingency learning for briefly presented stimuli (Parr & Mercier, 1998). Age-related changes in processing speed could mask older adults' sensitivity to the temporal contiguity between their response and the outcome. If older adults are still engaged in selecting and executing their response choice when a temporally contiguous outcome occurs, their ability to encode the outcome and form R–O associations would be limited. With a longer RPI, the benefit of strong temporal contiguity in older adults' causal learning may be more apparent.

Experiment 1

Method

Participants

Forty-eight young adults recruited from psychology classes at Western Kentucky University received course credit and a small monetary stipend for their participation. Forty-eight older adults recruited from the community 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. Biographical and cognitive ability data for the two groups are shown in Table 1.

Half of the participants in each age group were randomly assigned to each RPI condition; and within each RPI condition, half were randomly assigned to each outcome delay (OD) condition. To ensure that age differences in basic cognitive abilities were uniform across the conditions in this experiment, a 2 (age) × 2 (RPI) × 2 (OD) multivariate analysis of variance (MANOVA) was conducted for the measures of processing speed, working memory, verbal knowledge, and associative learning. As the data in Table 1 suggest, age was the only significant effect in this analysis, $F(6, 61) = 19.69$, $\eta^2 = .66$; all other effects, $F \leq 1.24$.

Materials and Design

Participants were given an RPI of either 750 ms (RPI-750) or 2,250 ms (RPI-2250) and an OD of either 1,000 ms (OD-1000) or 4,000 ms (OD-4000). Contingency was determined using the formula $\Delta RO = P(O/R) - P(O/{\sim}R)$, and the conditional probabilities of .125 and .875 were combined orthogonally to produce two causal learning problems with noncontingent relationships (.125–.125; .875–.875), one with a negative or preventative contingency ($-.75 = .125 - .875$) and one with a positive or generative contingency ($+.75 = .875 - .125$). Participants completed all problems, and a software randomization routine determined the order of administration individually for each participant.

A 10-trial, noncontingent practice problem preceded the presentation of the four, 60-trial test problems. In each problem, the beginning of a trial was signaled by the appearance of a white equilateral triangle with 1-inch sides outlined in black in the middle of a white screen and a row of small, filled black boxes at the bottom of the screen. The filled boxes emptied sequentially to mark the amount of time left in the RPI. Participants made a response by pressing the spacebar on a computer keyboard, and an outcome occurred when the triangle flashed from white to black and then back to white. When the spacebar was pressed during the RPI, it initiated the specified OD, and the outcome occurred at the end of this interval according to the programmed P(O/R). When the spacebar was not pressed, the end of the RPI initiated the OD, and the outcome occurred after this interval according to the programmed P(O/~R). In both cases, the outcome was determined by a software random number routine, so the actual probabilities of P(O/R) and P(O/~R) could vary slightly from the programmed probabilities. A trial ended after the occurrence of the outcome event (i.e., O or ~O), and a blank screen was displayed for 1,000 ms between trials. At the end of the problem, a rating scale with a slider bar positioned at the labeled center point of 0 (no relation) appeared on the screen. The rating scale was divided into 10 numerical sections on either side of the center point with labeled end points of –100 (prevents) and +100 (causes).

Procedure

Participants were tested individually in two sessions scheduled approximately 1 week apart. In the first session, participants completed a biography and health questionnaire and the causal learning task. In the second session, they completed tests of processing speed, working memory, semantic knowledge, and associative learning (see Table 1). Before beginning the practice problem for the causal learning task, participants were given instructions about the nature of the task and a demonstration of the response and outcome events. They were told that they would receive several problems in which they would have to discover whether pressing the spacebar on a keyboard had any effect on whether a triangle on the monitor screen flashed. They were then given a demonstration of the triangle flashing when they pressed the spacebar and flashing of its own accord when they did not press the spacebar. Participants were told that at the beginning of each trial in a problem, they would see the triangle and a row of small, filled boxes at the bottom of the screen. They were instructed that they should choose to press or not press the spacebar during the trial but that in order to learn the R–O causal relationship, they must determine what happened to the triangle both when they pressed and when they withheld pressing this key. They were also told that the filled boxes on the screen would empty sequentially to show the amount of time remaining for their response choice. Next, the participants were shown the causal rating scale and instructed that at the end of each problem, they would use the scale to rate the R–O causal relationship. They were informed that the end point of –100 meant that pressing the spacebar always prevented the triangle from flashing, that the end point of +100 meant that pressing always caused the triangle to flash, and that the center point of 0 meant that pressing had no effect on whether the triangle flashed. They were asked to record their rating of the strength and direction of the R–O relationship by moving the slider bar to the appropriate location on the rating scale. Participants were told that the relationship between their response and the outcome would not change within a problem but that it might differ from one problem to the next and they should not let the perceived relationship for one problem affect their ratings for the other problems. Finally, they were told that the accuracy of their causal ratings was important and that they would earn $0.25 for each accurate rating. Credit was given for ratings within ±.10 of the actual contingency. Participants were allowed to take up to a 2-min break between the problems, and after completing the causal learning task, they were told how much they had earned for accurate ratings.

Results and Discussion

Unless otherwise indicated, a criterion value of $p \leq .05$ was used for all analyses.

Causal Ratings

Mean causal ratings were computed for the two problems with noncontingent relationships. These ratings and those for the preventative and generative contingencies are shown in Figure 2. These data were entered into a 2 (age) × 2 (RPI) × 2 (OD) × 3 (contingency) analysis of variance (ANOVA). Older adults' causal ratings were more positive overall than those of young adults, $F(1, 88) = 9.02$, mean squared error (MSE) = .11, $\eta^2 = .09$, a consequence of their higher ratings for the preventative contingency. RPI and OD had no main effect on causal ratings, they did not interact with each other, and neither interacted with age: RPI × OD, Age × RPI, Age × OD, all Fs$(1, 88) < 1$, $MSE = .12$, $\eta^2 = .00$; Age ×

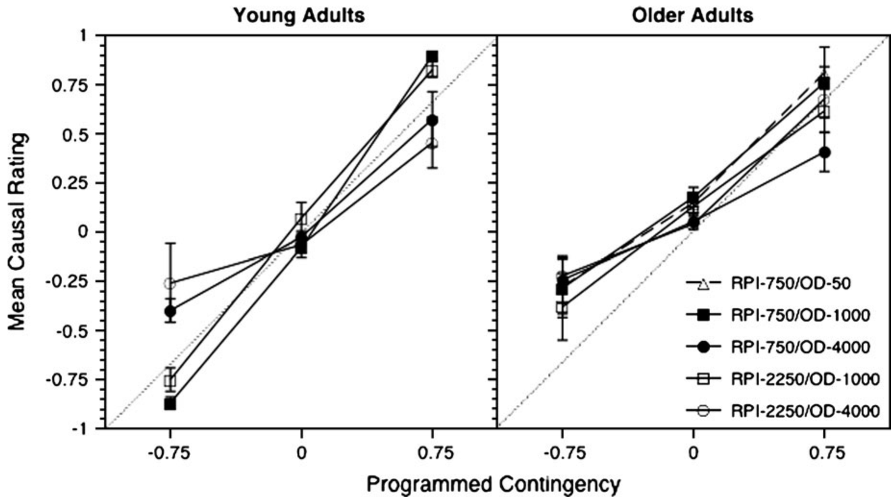

Figure 2. Young and older adults' mean causal ratings and standard errors for negative, zero, and positive contingencies in the response preparation interval (RPI) by outcome delay (OD) conditions in Experiments 1 and 2.

RPI × OD, $F(1, 88) = 2.86$, $\eta^2 = .03$. Ratings were strongly influenced by the programmed R–O contingency, $F(2, 176) = 176.98$, $MSE = .16$, $\eta^2 = .67$, suggesting that participants in both age groups perceived differences in the contingencies used in the causal learning problems. However, the ability to discriminate contingency varied with both age, Age × Contingency, $F(2, 176) = 4.98$, $\eta^2 = .05$; and OD, OD × Contingency, $F(2, 176) = 11.49$, $\eta^2 = .12$. Moreover, the effect of OD on contingency discrimination varied for young and older adults, Age × OD × Contingency, $F(2, 176) = 3.25$, $\eta^2 = .04$). No other interactions with contingency were significant (all *F*s < 1.11), showing that the RPI had no reliable effect on contingency discrimination for either young or older adults.

Isomorphism between causal ratings and programmed R–O contingency is reflected by a linear trend of contingency (Wasserman et al., 1983). To determine whether the source of the Age × OD × Contingency interaction might be due to age differences in the linear trend of contingency in causal ratings for the two ODs, we conducted a 2 (age) × 3 (R–O contingency) ANOVA with polynomial contrasts on the interaction effect for each OD condition. The slope of the young adults' causal rating function was steeper than that of older adults' in the OD-1000 condition, $F(1, 46) = 23.27$, $MSE = .11$, $\eta^2 = .34$; but not in the OD-4000 condition, $F(1, 46) < 1.00$. Thus, with a short OD, young adults were better at discriminating contingency than older adults, whereas with a long delay the young adults' performance advantage disappeared. To explore whether a short OD was indeed more advantageous to young than older adults' contingency discrimination, we conducted a 2 (OD) × 3 (contingency) ANOVA for each age group with polynomial contrasts on the interaction effect. For young adults, the slope of the causal rating function in the OD-1000 condition was substantially steeper than in the OD-4000 condition, $F(1, 24) = 32.30$, $MSE = .06$, $\eta^2 = .57$; but for older adults, there was no significant difference between these slopes, $F(1, 46) = 1.58$, $MSE = .23$, $\eta^2 = .03$.

Although the trend analysis suggests that temporal contiguity had a greater effect on young than older adults' discrimination of causal contingency, examination of Figure 2 suggests that this finding is due primarily to group differences for the preventative contingency. To investigate this possibility, we conducted analyses of the simple interaction effect of age and OD for each contingency. This interaction was significant for the −.75 contingency, $F(1, 92) = 3.94$, $MSE = .22$, $\eta^2 = .04$; and comparisons of age effects within each OD condition indicated that young adults' ratings were more negative than older adults' ratings in the OD-1000 condition, $F(1, 46) = 25.83$, $MSE = .11$, $\eta^2 = .36$, but not in the OD-4000 condition, $F(1, 46) < 1.00$. There was no Age × OD interaction when response and outcome were noncontingent, $F(1, 92) < 1.00$. Older adults' ratings were more positive than young adults' ratings, $F(1, 92) = 9.04$, $MSE = .05$, $\eta^2 = .09$; and ratings were marginally higher in the OD-1000 than the OD-4000 condition, $F(1, 92) = 3.10$, $p = .08$, $\eta^2 = .03$. Finally, there was no difference in young and older adults' ratings for the +.75 contingency, $F(1, 92) < 1.00$, and ratings for both groups were more positive in the OD-1000 condition than the OD-4000 condition: OD, $F(1, 92) = 9.82$, $MSE = .15$, $\eta^2 = .10$; Age × OD, $F(1, 92) = 1.65$, $\eta^2 = .02$. Thus, with a short OD, both young and older adults gave higher causal ratings for the generative contingency; however, only young adults gave lower causal ratings for the preventative contingency.

Response Preparation and Sampling

We examined short and long RPIs to determine whether older adults' response to contiguity might be masked by too

Table 2. Mean Response Preparation Times for RPI-750 and RPI-2250 Conditions in Experiments 1 and 2

	Programmed R–O Contingency		
	−.75	.00	.75
RPI-750			
Young (Experiment 1)	374.97 (11.20)	384.77 (13.61)	389.53 (14.78)
Older (Experiment 1)	404.13 (16.36)	393.67 (16.28)	396.24 (14.19)
Older (Experiment 2)	381.73 (22.32)	371.96 (21.67)	378.34 (26.22)
RPI-2250			
Young (Experiment 1)	969.81 (34.49)	1,009.13 (46.80)	1,000.66 (52.69)
Older (Experiment 1)	1,063.46 (50.37)	1,010.00 (42.61)	1,076.13 (49.54)

Note: Standard error is in parentheses.

Table 3. Mean Response Probabilities for RP-750 and RPI-2250 Conditions in Experiments 1 and 2

	Programmed R-O Contingency		
	−.75	.00	.75
RPI-750			
Young (Experiment 1)	.52 (.04)	.49 (.03)	.54 (.04)
Older (Experiment 1)	.55 (.04)	.57 (.04)	.53 (.05)
Older (Experiment 2)	.49 (.04)	.51 (.06)	.51 (.06)
RPI-2250			
Young (Experiment 1)	.53 (.04)	.50 (.03)	.53 (.04)
Older (Experiment 1)	.55 (.04)	.55 (.04)	.59 (.04)

Note: Standard error is in parentheses.

little time to prepare a response. This clearly was not the case—the length of the RPI had no reliable effect on either group's contingency discrimination in either contiguity condition. Another question of interest is whether there were age differences in the amount of time taken to select and execute a response within the RPI. We therefore calculated each participant's mean key press reaction time for each problem and submitted these data to a 2 (age) × 2 (RPI) × 2 (OD) × 3 (contingency) ANOVA. As the data in Table 2 show, response times were shorter overall in the RPI-750 than in the RPI-2250 condition, but no other effects involving this variable were significant: RPI, $F(1, 87) = 493.94$, $MSE = 57{,}191.64$, $\eta^2 = .85$. In each condition, both young and older adults executed their responses near the middle of the RPI. It thus appears that older adults had ample time to prepare and execute a response, even in the short RPI condition.

One other aspect of our participants' response patterns during the RPI might have affected their ability to make accurate causal ratings. If one group chose to execute a response less often than to withhold a response, this group would have sampled P(O/R) less effectively. To determine whether this occurred, we calculated the probability of key pressing for each problem for each participant. A 2 (age) × 2 (RPI) × 2 (OD) × 3 (contingency) ANOVA for these data revealed no significant main or interaction effects: all effects, $F \leq 1.97$. As the data in Table 3 show, both young and older participants chose to execute and withhold responses in almost equal proportions. This finding rules out the possibility that one or both of these groups sampled P(O/R) less effectively.

Experiment 2

Temporal contiguity moderated older adults' generative causal ratings but not their preventative causal ratings. In preventative causal learning, the activation of absent cue and outcome representations is especially important. It is possible that even with the relatively short R–O interval in the OD-1000 condition, older adults had difficulty maintaining the activation of these representations long enough to acquire an association between them. To determine whether older adults' preventative causal learning would improve if the outcome event occurred immediately after the response or the end of the RPI, we compared the contingency discrimination of the older adults in the RPI-750/OD-1000 condition with that of older adults who were given an RPI of 750 ms and an OD of 50 ms.

Method

Participants

Twelve older adults were recruited and screened in the same way as those in Experiment 1. Biographical and cognitive ability data for these participants are shown in Table 1. A MANOVA comparing the cognitive ability scores for this sample of older participants with those of the older participants in the RPI-750/OD-1000 group in Experiment 1 revealed no differences between the two OD groups, $F(5, 18) < 1.00$.

Materials and Design

The problems administered to the participants in this experiment were identical to those administered in Experiment 1 except that only the 750 ms RPI was used and the OD was reduced to 50 ms.

Procedure

The procedure was identical to that used in Experiment 1.

Results and Discussion

The mean response times and response probabilities for this group are shown in Tables 2 and 3, and causal ratings are shown in Figure 1. Response times and response probabilities for the older participants in the RPI-750/OD-50 group were similar to those for the RPI-750/OD-1000 group in Experiment 1 (all tests, $F < 1.00$). Although there appeared to be a small increase in older adults' causal ratings for the generative causal contingency, a 2 (OD) × 3 (contingency) ANOVA showed that their ratings were virtually identical in the two OD conditions (all tests involving OD, $F < 1.00$). A 2 (age) × 3 (contingency) ANOVA comparing older adults' ratings for the RPI-750/OD-50 condition with younger adults' ratings for the RPI-750/OD-1000 condition revealed that age differences were still present in contingency discrimination: Age × Contingency, $F(2, 48) = 15.82$, $MSE = .06$, $\eta^2 = .40$. Thus, an immediate outcome produced no further improvement in older adults' contingency discrimination and did not help them learn the preventative causal contingency.

Discussion

The results of this study are consistent with the idea that both contingency and contiguity are important cues to causality. Contingency was determined by differences in the relative frequencies of response–outcome event combinations over the learning trials in a problem. For the generative contingency, there were more RO trials than R~O trials as well as more ~R~O trials than ~RO trials, so the predictive value of the response aggregated over trials was excitatory. For the preventative contingency, there were more R~O and ~RO trials than RO and ~R~O trials, so the predictive value of the response aggregated over trials was inhibitory. Both young and older adults used this contingency information in their causal ratings. As in earlier studies (Mutter & Williams, 2004; Mutter et al., 2006, 2007), they discriminated generative and preventative causal contingencies from each other and from the noncontingent relationship. Moreover, in line with previous findings (e.g., Buehner & McGregor, 2005; Shanks et al., 1989), temporal contiguity moderated but did not override the contingency information. Both groups were sensitive to differences in contingency even when the response and outcome were noncontiguous. Despite these similarities, the moderating effect of temporal contiguity on generative and preventative causal learning varied for the two groups. There were no age differences in causal ratings for the generative causal contingency, and ratings for both young and older adults converged toward zero when the response and outcome were noncontiguous. This suggests that age differences in associative learning processes for generative causal relationships were relatively minor and that the temporal relationship between response and outcome affected young and older adults' ability to accomplish these processes in much the same way. However, there seems to be a fundamental age-related decline in these processes for preventative causal learning, as even the strongest temporal contiguity did not help older adults learn this relationship.

As noted previously, temporal contiguity in generative learning produces frequent conjoint A1 activation states for response and outcome representations in working memory, leading to an aggregate excitatory associative value for the response (Aitken & Dickinson, 2005; Dickinson & Burke, 1996; Wagner, 1981). With a delayed outcome, the response representation may occasionally be in the A2 activation state when the outcome occurs, producing an increase in its inhibitory associative value, or the representation may have returned to the inactive state, preventing the formation of an association. In either case, causal ratings would converge toward zero. The fact that variations in temporal contiguity moderated generative causal learning for both young and older adults suggests that age causes little or no disruption in these activation and association processes for representations of responses and outcomes that are *physically* present during learning trials.

In contrast, the sizable age difference in preventative causal learning and the fact that temporal contiguity did not moderate this learning for older adults suggests that age does disrupt activation and association processes for the representations of absent events. These representations are activated to the A2 state when they are retrieved by the context or by other associated events (Wagner, 1981). Thus, effective cue utilization is crucial to the retrieval of absent events. There is considerable evidence for age differences in the use of retrieval cues (e.g., Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000; Thomas & Bulevich, 2006) and it has been suggested that this may be due to a decline in older adults' ability to recover the context in which items have been encoded (Kahana, Howard, Zaromb, & Wingfield, 2002). A recent experiment by Provyn, Sliwinski, and Howard (2007) demonstrates how this deficiency affects older adults' associative learning. When given double-function paired associates (A–B, B–C), the context retrieved by the presentation of B should cue recall of A and C, leading to the acquisition of both backward (B–A) and remote (A–C) associations. However, older adults are less likely than young adults to produce recall intrusions reflecting these associations, suggesting less efficient use of the context as a cue for the retrieval of the absent items. In similar fashion, the older adults in the present study may have been less efficient at using the trial context or the explicitly presented outcome to activate the representation of the absent response to the A2 state. This would affect the aggregation of inhibitory associative value in preventative causal learning to a greater extent than excitatory associative value in generative causal learning. Moreover, greater contiguity between the response and outcome would not ameliorate this basic deficit in the ability to retrieve absent events.

We have adopted the framework of the R-W model and its variants, SOP and mSOP, to explain our findings. There are, of course, other models of contingency and contiguity in causal learning that could apply, but we do not think these models offer the same level of explanatory power. For example, the temporal coding hypothesis proposed by Miller and his colleagues (Miller & Barnet, 1993; Savastano & Miller, 1998) suggests that associations incorporate representations of the various types of relationships between event pairs, including their associative strength (i.e., contingency) and their temporal proximity and order. The encoded temporal relationships give rise to expectations about the duration of the interval between these events. Causal learning not only involves acquiring knowledge of *whether* an outcome will occur but also involves acquiring knowledge of *when* it will occur (Young, Rogers, & Beckmann, 2005). By this view, variation in the effects of age and contiguity on generative and preventative causal learning could occur because older adults encode both contingency and temporal information for generative causal contingencies but are less effective at encoding this information for preventative contingencies. However, this model offers no further detail to help clarify what aspects of cognitive aging might give rise to differences in encoding contingency and temporal information for the two types of causal learning.

On a final note, there is extensive evidence from both animal and human studies that circuitry in frontal and medial temporal lobes is associated with contextual associative learning and retrieval (for a review of this literature, see Howard, Fotedar, Datey, & Hasselmo, 2005; Luu, Pirogovsky, & Gilbert, 2008; Mitchell et al., 2000). For example, Phillips and LeDoux (1992) found that although hippocampal-lesioned rats learned to fear a tone presented with a foot shock, they did not learn to fear the contextual stimuli that were consistently present during this fear conditioning. Likewise, deficits in older adults' feature binding, which is a crucial aspect of memory for the context or source of information, are associated with lower activation in the left anterior hippocampus and right prefrontal cortex (Mitchell et al., 2000). This raises the interesting possibility that the age difference seen in preventative causal learning in this and other studies (e.g., Mutter & Williams, 2004; Mutter et al., 2006; 2007) is another example of the general decline in contextual learning and retrieval precipitated by age-related changes in the structure and function of these regions of the brain (e.g., Driscoll et al., 2003; Raz, 2000). Further elucidation of how these changes affect older adults' ability to retrieve the representations of absent events and form the inhibitory associations that are necessary for preventative causal learning offers a promising avenue for future research.

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