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# The Effects of Age and Task Timing Characteristics on Contingency Judgment

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THE EFFECTS OF AGE AND TASK TIMING CHARACTERISTICS  
ON CONTINGENCY JUDGMENT

A Thesis  
Presented to  
The Faculty of the Department of Psychology  
Western Kentucky University  
Bowling Green, Kentucky

In Partial Fulfillment  
Of the Requirements for the Degree  
Master of Arts

by  
Marci C. Sammons

August, 2004

THE EFFECTS OF AGE AND TASK TIMING CHARACTERISTICS ON  
CONTINGENCY JUDGMENT

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# THE EFFECTS OF AGE AND TASK TIMING CHARACTERISTICS ON CONTINGENCY JUDGMENT

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Detecting contingency relationships between causal events allows us to adapt to and control these events. However, research has shown age-related impairments in this ability. The goal of this study was to examine how reduced processing speed in older adults affects contingency learning. Manipulating the time during which to generate the response, to test the limited time mechanism of processing speed, had little effect on contingency judgments. Varying the temporal contiguity of events, to test the simultaneity mechanism of processing speed, affected young adults' contingency judgments. Older adults' judgments were less accurate overall, and young adults' judgments were similarly less accurate when there was less temporal contiguity of events. These findings lend support for a processing speed theory of contingency learning.

## Chapter One

### Introduction

The literature on cognitive aging provides considerable evidence that old age is associated with decline in an array of cognitive abilities. Among these age-related cognitive impairments is an apparent decline in the ability to learn relationships between causal events in the environment (e.g., Mutter & Pliske, 1996). Because humans rely on such capabilities to adaptively predict, explain, and control the events they encounter (Alloy & Tabachnick, 1984), and because the environment changes continuously, this ability remains essential even in the later years of life. Psychological research can provide a greater understanding of cognitive aging processes so that age-related changes can be better accommodated. Indeed, by providing a greater understanding of this aspect of cognition, psychologists may not only help older adults distinguish normal changes in cognition from those that are abnormal, but they may also increase the general understanding of normal human cognition, thereby improving standards of living for all age groups.

In an attempt to identify potential reasons for a decline in contingency learning ability, research has indicated slowed processing speed. Indeed, a large amount of research has documented an age-related decline in processing speed (e.g., Birren, 1974). Furthermore, research has shown an empirical link between processing speed and associative learning, with slower processing speed yielding impaired associative learning ability (Fisk & Warr, 1996; Kyllonen et al., 1991; Salthouse, 1994b). In addition to these findings, research has found that associative learning ability is related to contingency

learning accuracy (e.g., Rescorla, 1972; Shanks, 1987). Taken as a whole, these findings suggest that there is also a link between processing speed and contingency learning.

Interestingly, the few studies examining this link have shown that constraining processing time and decreasing temporal contiguity of causal events reduces contingency judgment accuracy in young and older adults (e.g., Parr & Mercier, 1998).

Taking these findings into consideration, the current study further examined how age-related reductions in processing speed affect contingency judgment accuracy. With the integration of a processing speed theory of associative learning (Salthouse, 1996) and associative learning theories of contingency learning (Shanks, 1987; Wagner, 1981), the impact of processing speed mechanisms on contingency judgment accuracy were investigated. Specifically, the timing characteristics of the contingency judgment task were manipulated to examine the differential impact of the limited time and simultaneity mechanisms of processing speed (i.e., Salthouse, 1996) on contingency judgments. The limited time mechanism was tested by altering how much time both younger and older adults had to generate a response (generation time). It was hypothesized that participants with slower processing speed would be differentially taxed when given a short time to process the first event, resulting in less accurate contingency judgments. However, the opposite was predicted of participants that are provided a longer response generation time. The simultaneity mechanism was tested by manipulating the length of time between the response and outcome events (memory time). It was expected that participants with slower processing speed would be less able to maintain the memory activation for the first event through rehearsal over a longer response-outcome interval but that all participants would be able to associate the two events with a short response-outcome

interval, because the event representations overlap more easily in working memory.

Because older adults generally have slower processing speed, it was specifically expected that contingency judgment accuracy would be more dramatically reduced in older adults than younger adults in situations in which they were especially bound by time constraints—when they had less time to process the causal events and when there was less temporal contiguity of the events.

## Chapter Two

### Literature Review

#### *Contingency Learning*

##### Definition of Contingency Learning

Contingency learning involves the detection and retention of relationships between co-occurring events in the environment. Contingencies are ever-present in our daily surroundings and are involved in judgments ranging from everyday social interactions to complex medical diagnoses. Judgments of contingency underlie prediction, explanation, and control over events (Alloy & Tabachnick, 1984) and are therefore essential to many behaviors, such as learning, categorization, and hypothesis testing (Crocker, 1981). Thus, contingency learning is central not only to the regulation and understanding of events in what may otherwise seem a senseless world but also to the adaptation of the self to new environmental events.

The focus of many contingency judgment studies has been on causal learning. Some of these studies have involved passive observation of probabilistic causal relationships present in the environment; others have involved behavioral control of contingent relationships. This distinction is commonly labeled cue-outcome (C-O) versus response-outcome (R-O) contingency learning. Although both C-O and R-O contingency learning enable us to predict and explain occurrences of outcome events, R-O learning is unique in that one's behavior is or is not causing the outcome, so predictive learning can be facilitated through one's own behavior. Both C-O and R-O contingency judgments

have been studied extensively in young adults (e.g., Allan & Jenkins, 1980), but there has been little aging research in either of these areas, especially R-O contingency learning.

Contingency is defined statistically in terms of the  $\Delta P$  rule—the difference between the conditional probability of an outcome given a cue or response and the conditional probability of an outcome given no cue or response:  $\Delta P = P(O/CR) - P(O/\sim CR)$ . Proponents of a rule-based explanation of contingency judgment claim that humans “compute”  $\Delta P$  when making judgments of contingency (e.g., Allan & Jenkins, 1980; Wasserman, Chatlosh, & Neunaber, 1983). The conditional probabilities are obtained from the frequencies of four possible cue or response/outcome combinations (see Figure 1). The probability of an outcome, given a cue or response has occurred, would be computed as the number of times an outcome occurred when the cue or response occurred (cell A), divided by the total number of times the cue or response event had occurred (cell A plus cell B):  $P(O/CR) = (A / A+B)$ . Similarly, the probability of an outcome when no cue or response has occurred is computed by the number of times the outcome occurred in the absence of the cue or response (cell C) divided by the total number of times no cue or response occurred (cell C plus cell D):  $P(O/\sim CR) = (C / C+D)$ .

		Outcome	
		<i>O</i>	<i>~O</i>
Cue or Response	<i>CR</i>	<b>A</b>	<b>B</b>
	<i>~CR</i>	<b>C</b>	<b>D</b>

*Figure 1.* CR-O Contingency Table.

The contingency between two events may be anything between positive and negative 1.0. When an outcome is more likely in the presence of a cue or response, or when the cue or response causes the outcome, the contingency between the events is positive. When the outcome is more likely in the absence of a cue or response, or when the cue or response inhibits the outcome, the contingency is negative. When there is no relationship between the cue or response and outcome events, the contingency is zero.

#### Research on R-O Contingency Learning in Young Adults

A number of studies have focused on R-O contingency learning in young adults, showing that young adults learn causal contingencies with remarkable accuracy (e.g., Allen & Jenkins, 1980; Chatlosh, Neunaber, & Wasserman, 1985; Wasserman, Chatlosh, & Neunaber, 1983; Wasserman, Elek, Chatlosh, & Baker, 1993). For example, Chatlosh, Neunaber, and Wasserman (1985, Experiment 1) used nine contingency problems, computed from all possible combinations of .875, .50, and .125 conditional probabilities, and asked participants to rate an R-O relation of the extent to which pressing a telegraph key caused a white light to flash. They found that 98% of the variance in young adults' contingency judgments was accounted for by a linear trend of actual contingency.

Other studies on contingency learning in young adults have highlighted some learning conditions that reduce the accuracy of young adults' contingency judgment performance. Of particular interest to the present study, researchers have found a decrease in judged contingency as the time between response and outcome is increased (e.g., Shanks & Dickinson, 1991; Shanks, Pearson, & Dickinson, 1989, Experiment 2). For example, to test the sensitivity of causality judgments to temporal contiguity, Dickinson and Shanks (1985) used a video game in which participants did or did not fire

a shell (response) and a tank did or did not explode after traversing a minefield (outcome).  $P(O/R)$  was considered how effective the shell was or how dense the minefield was, whereas  $P(O/\sim R)$  reflected only differences in how dense the minefield was.  $P(O/R)$  was always set at .75, and  $P(O/\sim R)$  varied between .75 and .25. They examined an immediate condition in which firing the shell caused an explosion immediately (250 ms) while the tank was still crossing the minefield, a delayed condition in which firing the shell caused an explosion after the tank traversed the entire minefield and would have disappeared from sight anyway (700 ms), and a random condition in which the tank exploded at a randomly determined time as it traversed the screen. In all conditions, if the shell was not fired, the tank exploded at a randomly determined time according to the conditional probability of an outcome given no response. As expected, contingency judgment accuracy was significantly higher in the immediate condition than in the delayed and random conditions, which did not differ, lending support for the importance of event contiguity for causal contingency judgment.

### *Associative Processes in Contingency Learning*

Although contingency judgments may involve computations based on learned frequencies of events (e.g., Allan & Jenkins, 1980), contingency detection may also be explained by a simpler associative learning mechanism that dynamically updates associative strength between two co-occurring events (e.g., Rescorla, 1985). According to associative learning theories, associative learning is a connective mechanism that links initially disparate entities or events (Rescorla, 1985). For associative learning to occur, stimulus and response representations must be simultaneously activated in working

memory (i.e., Frensch & Miner, 1994; Sloman, 1996; Wagner, 1981). Research has shown that associative learning depends on influences such as prior experience (Kausler, 1994), stimulus intensity (e.g., Finkbiner & Woodruff-Pak, 1991), and spatial or temporal contiguity of events (Finkbiner & Woodruff-Pak, 1991; Sloman, 1996). Because contingency learning may be explained by the associative learning paradigm, it is useful to survey the basic mechanisms of associative learning and how these have been applied to contingency learning.

### Rescorla-Wagner Model

The Rescorla-Wagner (1972) theory of classical conditioning suggests that when events co-occur, an association is formed between the representations of the events in memory (Rescorla, 1985). The theory explains the learning processes in Pavlovian conditioning but can also be applied to instrumental learning (Miller, Barnet, & Grahame, 1995; Rescorla, 1985). This model represents changes in the associative strength of a target stimulus by the equation  $\Delta V = \alpha \beta (\lambda - V)$ , where  $\alpha$  is a constant related to the salience of this stimulus,  $\beta$  is a constant related to the salience of the outcome,  $\lambda$  is the asymptote or maximum amount of associative learning the outcome will support, and  $V$  is the total amount of associative strength accrued to the target stimulus going into a particular trial (Rescorla & Wagner, 1972). In early learning trials,  $V$  will be small, making  $\lambda - V$  large and the resulting change in associative strength ( $\Delta V$ ) large. Over subsequent learning trials, when  $V$  has become increasingly stronger and thus closer to asymptote,  $\Delta V$  will become smaller and will begin to level off (Rescorla & Wagner, 1972). As such, the Rescorla-Wagner theory of classical conditioning accounts for

changes in the rate of learning over multiple trials (i.e., the typical learning curve; e.g., Shanks, 1987).

According to this model, two associations are acquired during the process of associative learning: (1) an association between a compound stimulus—representing the target stimulus together with the background context and the outcome ( $V_{BT}$ ), and (2) an association between the background context alone and the outcome ( $V_B$ ) (Rescorla & Wagner, 1972). In other words, when a target response occurs, it is encoded along with the context of the experimental situation in which it occurs; when a response does not occur, the background context alone is encoded. Rescorla and Wagner (1972) conceptualized the associative strength of the compound stimulus ( $V_{BT}$ ) as related to the strength of its component parts ( $V_{BT} = V_B + V_T$ ). Thus, the amount of associative strength that can accrue to the target depends on the strength of the association between the background and outcome. If the background alone does not reliably predict the outcome, the associative strength of the target response will be high; if the background by itself reliably predicts the outcome, the associative strength of the target response will be low. Hence, in a positive contingency, the outcome is more likely to happen when the response target and background are present together (strong  $V_{BT}$ ) and is less likely to occur when the background occurs alone (weak  $V_B$ ), yielding heightened associative strength with the target. Conversely, in a negative contingency, the outcome is more likely to result when the target stimulus is absent and the background occurs alone. In this case, accrual of associative strength to the target response is blocked, and the R-O association is weakened because the background is a better predictor of the outcome (Rescorla, 1985).

### Shanks' $J_t$ Model

Shanks' (1987)  $J_t$  model applied the principles of the Rescorla-Wagner (1972) model of classical conditioning to human contingency learning and judgment and is currently regarded as the most accurate account of causal contingency detection in humans (Mutter & Williams, 2004). Like the Rescorla-Wagner model, Shanks (1987) posited that a series of contingency learning trials allows two associations to be formed: (1) an association between the target plus the background and the outcome ( $V_{bt}$ ) and (2) an association between the background alone and the outcome ( $V_b$ ). Hence, as the formula  $J_t = V_{bt} - V_b$  illustrates, judgments of causality ( $J_t$ ) are based on an assessment of the difference in strength between these two associations. Shanks' model, like the Rescorla-Wagner theory, holds that the strengths of the  $V_{bt}$  and  $V_b$  associations are affected by learning rate or salience parameters ( $a$  and  $b$ ) and the asymptote ( $\lambda$ ) of associative strength that can be supported:  $\Delta V_b = a_b b (\lambda - V_b)$  and  $\Delta V_{bt} = a_{bt} b (\lambda - V_{bt})$ . Thus, this model predicts that judgments of causality will decrease when the contingency is reduced, because the difference between  $V_{bt}$  and  $V_b$  will decrease as a consequence of the increase in associative strength between the outcome and the background ( $V_b$ ).

As Dickinson and Shanks (1985) note, this associative model of contingency learning combines advantages of conditioning theory and the  $\Delta P$  rule; indeed, at first glance the equations appear equivalent. After all, the probability of an outcome given a response,  $P(O/R)$ , is essentially the same as the associative strength held between the target plus background and the outcome, or  $V_{bt}$ . Likewise, the probability of an outcome given no response,  $P(O/\sim R)$ , is similar to the associative strength held between the background alone and the outcome,  $V_b$ . And  $\Delta P$  and  $J_t$  are computed by subtracting the

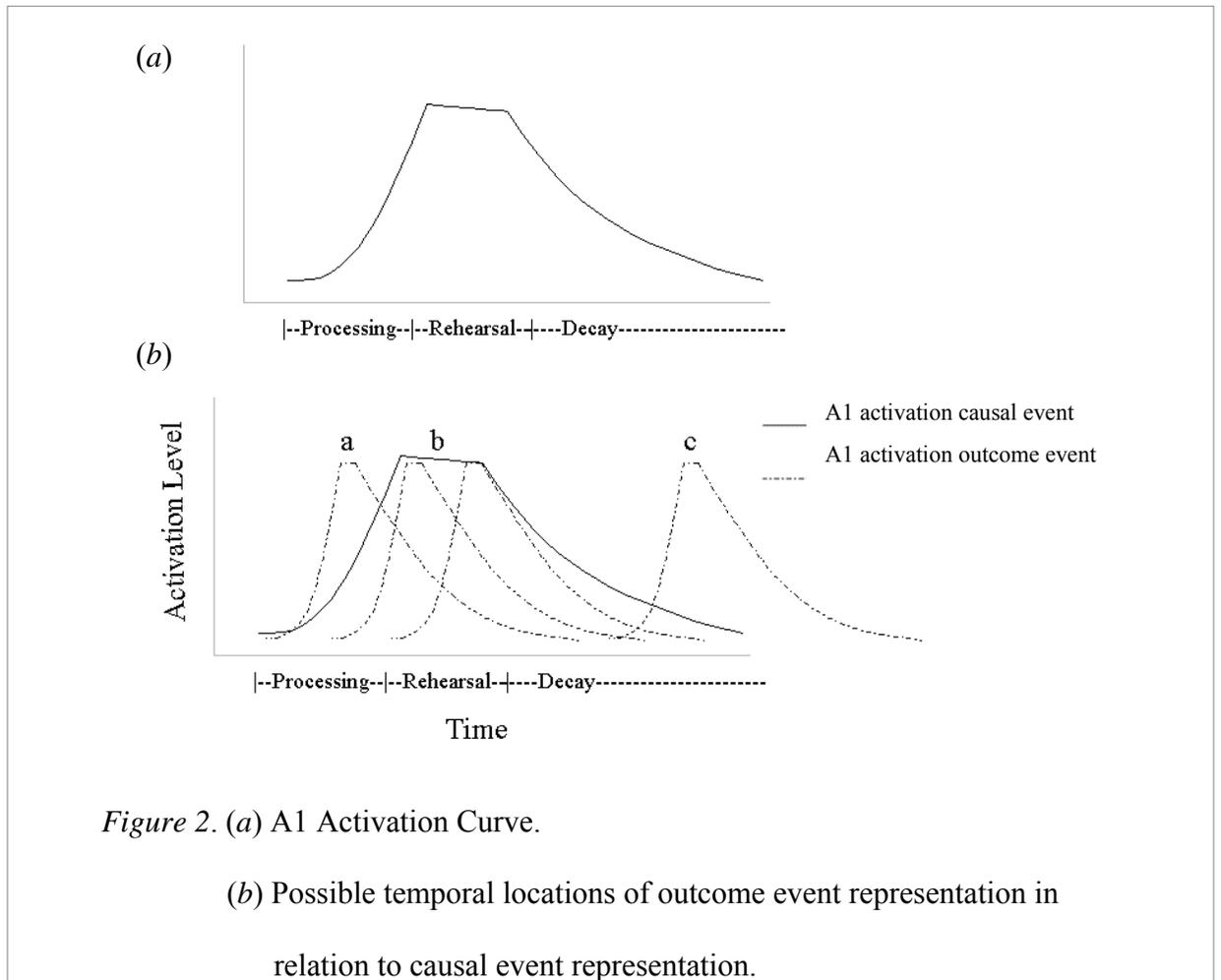
two. But while the component parts mean essentially the same thing, their constitutions are quite different. As defined previously,  $P(O/R)$  and  $P(O/\sim R)$  are conditional probabilities computed from relative cell frequencies in a contingency table. In contrast,  $V_b$  and  $V_{bt}$  change over trials as a function of additional learning rate parameters. Thus,  $J_t$ , unlike  $\Delta P$ , takes into account how the strength of association changes with amount of training. Furthermore, in contrast to the objective  $\Delta P$  rule, the  $J_t$  rule implies a selective attribution process that is modulated by the information about the causal context that is present whenever the target operates. Qualitatively, the associative model describes causal knowledge as being derived from competing associations between the representations of the events, whereas the  $\Delta P$  approach describes people as acquiring and comparing mental representations of two conditional probabilities (Shanks, 1987). Interestingly, Shanks (1987) concluded that the associative explanation of contingency learning actually does not require any mental representation of ‘contingency’ at all, since it is actually the degree of associative strength between the two events that is reflected in a causality judgment.

#### Wagner’s SOP Model

By providing information about how associative learning processes might operate from a cognitive viewpoint, Wagner’s (1981) Standard Operating Procedure (SOP) theory also extends the Rescorla-Wagner (1972) theory. Wagner (1981) suggested SOP as a set of standard operating procedures in memory. According to this theory, memory nodes operate in different states of activation (A1, A2, or I), and associative learning depends on which nodes are highly activated in working memory. Nodes in the A1 state of activation are most important to associative learning, because the A1 state is the

highest level of sensory activation in working memory, induced by stimulus onset and representing stimuli in focal attention. Nodes in the A2 state represent stimuli in working memory but not in focal attention. Generally, A2 activation follows A1 activation; however, the presentation of a stimulus can also lead to A2 activations in the representations of associated stimuli. Nodes in an I, or inactive, state represent information that has been stored in long-term memory yet has not been retrieved into working memory.

Using Wagner's (1981) terminology to describe causal learning, the presentation of a causal stimulus results in an A1 state of memory activation for the representation of that event in working memory. In the depiction shown in Figure 2, the upward slope corresponds to the processing of the event into focal attention, with the peak representing full A1 activation of the representation. Incidentally, A1 activation may be prolonged through rehearsal, as depicted by the plateau of the graph. Depending on how much the event is rehearsed, the activation eventually decays, as shown by the downward slope. When the outcome event occurs, its representation is also activated into an A1 state of activation. The A1 activation of the outcome stimulus representation could occur during one of three temporal locations in relation to the causal stimulus: (a) before this stimulus has been fully processed, (b) during the A1 activation of this stimulus, or (c) after the A1 activation of this stimulus has begun to decay. An association between the two events is formed only when the A1 activations of the causal and outcome events overlap in working memory, and the strongest association is made when the overlapping A1 peaks are at their highest levels.



### Research Support for Associative Learning Theory

The associative learning theory has shown a remarkable ability to predict and explain a wide variety of contingency learning data (e.g., Mackintosh, 1983, as cited in Rescorla, 1985; Rescorla, 1972; Wasserman et al., 1993). Shanks (1987), using a procedure similar to Chatlosh and colleagues (1985), tested both rule-based and associative models of contingency judgment acquisition by comparing actual contingency judgment data with simulated contingency judgments based on the respective models. The actual contingency judgment data followed growth functions, with positive contingency judgments increasing and negative judgments decreasing over trials. This overall acquisition pattern did not correspond to predictions based on the rule-based

models. Since the  $\Delta P$  rule involves computing contingency based on mental representations of conditional probabilities, it assumes that contingency estimates will be accurate after only a few learning trials. In fact, the mathematical calculations should be even more accurate with fewer trials, because it should be easier to remember how many times the outcome occurred with and without the response. In contrast, the associative model incorporates the idea that conditional probability estimates should regress toward the actual probabilities as more information is acquired (Shanks, 1987). Furthermore, the associative model allows for the acquisition of information about compound cues, which in this case would be the target response in addition to the background, as information about the context conveys whether the target is in fact an informative predictor of the outcome. In contrast, the  $\Delta P$  rule does not account for learning situations with multiple cues (Dickinson & Shanks, 1985). Shanks (1987) concluded that the associative model, because it more accurately accounted for the observed patterns of contingency learning, provides the best account of contingency learning and judgment.

Shanks' (1987) associative learning model can also explain the reduced accuracy of contingency judgments that typically accompanies decreased temporal contiguity. As described previously, Dickinson and Shanks (1985) asked young adult participants to judge how effectively firing a shell caused a tank to explode, manipulating the amount of time between firing the shell and the explosion of a tank. To further explore the associative learning model, Dickinson and Shanks (1985) created mean contingency ratings and mean values of associative strength ( $J_t$ ) of 500 simulated subjects under the same temporal conditions as the actual participants in their contingency task. Simulated judgments, as predicted by this simple  $J_t$  model, were similar to actual subject judgments

in their experiment. Because the temporal contiguity of the target and outcome events influenced the accuracy of contingency estimates, they concluded that the associative model indeed illustrates a way learning might be influenced by variations in the temporal relations between events. In contrast, a rule-based approach does not clearly explain why varying the time between events should affect the operations involved in computing contingency judgments (Dickinson & Shanks, 1985).

### *Age, Associative Processes, and Contingency Learning*

#### Contingency Learning and Aging

Although many studies have explored young adults' ability to detect causal relationships in the environment, fewer studies have examined older adults' ability to judge contingency. However, the studies that do exist show that although older adults can perceive contingent relationships in the environment, there is an age-related decline in this ability. Specifically, compared to young adults, older adults tend to underestimate contingency (e.g., Parr & Mercier, 1998), are less able to detect weak as opposed to salient contingencies (e.g., Mutter & Williams, 2004), show less accurate contingency judgments in situations requiring higher memory demand (Mutter & Pliske, 1996), and are less able to perceive negative contingencies (e.g., Chasseigne, Mullet, & Stewart, 1997; Mutter & Williams, 2004). Additionally, older adults seem to be less able to make explicit judgments of contingency than to adapt their responses to changing environmental contingencies (e.g., Mutter & Williams, 2004).

As noted previously, research provides substantial support for a link between associative learning capability and contingency judgment accuracy. The implication is

that contingency learning will be reduced if associative learning processes are impaired (Mutter & Williams, 2004). Moreover, there is considerable evidence that older adults show impairment in associative learning, lending support for an associative learning theory of impaired contingency learning in older adults.

### Age and Associative Learning

Simple measures of associative learning involve learning stimulus-response (S-R) pairs. In the realm of cognitive aging, associative learning is frequently measured by the paired-associate learning (PAL) task, involving intentional learning and recall of stimulus-response pairs over many trials (Kausler, 1994). Associative learning is also assessed in Pavlovian conditioning paradigms, such as eyeblink classical conditioning studies (e.g., Woodruff-Pak & Thompson, 1988). Other associative learning tasks involve pairing symbols (e.g., Conditional Associative Learning—Levine, Stuss, & Milberg, 1997; Salthouse, 1994b) or learning number-symbol relationships (e.g., Salthouse, 1994b).

Research has shown that associative learning is impaired by age (e.g., Hertzog et al., 2002). For example, paired associate learning studies show that older adults are less accurate than young adults after both single and multiple learning trials (Donlosky & Connor, 1997). Compared to young adults, older adults have more difficulty learning new associations (see Kausler, 1994), are slower and less accurate to respond to previously seen S-R pairs (Spieler & Balota, 1996), and are more apt to perseverate responses in previously learned S-R pairs to learning with a new R (see Kausler, 1994). Furthermore, increasing age may be associated with a more rapid loss of associative information over very short intervals (Salthouse, 1994b). Corroborating results have been found in

associative learning studies with eyeblink classical conditioning (Finkbiner & Woodruff-Pak, 1991; Woodruff-Pak & Jaeger, 1998; Woodruff-Pak & Thompson, 1988). The age-related decline in classical conditioning was found in both delay conditioning (Woodruff-Pak & Thompson, 1988) and in trace conditioning (Finkbiner and Woodruff-Pak, 1991, Experiment 2) when the period between conditioned and unconditioned stimuli varied between 400 and 1800 milliseconds. Interestingly, Mutter and Williams (2004) found that older adults' contingency detection was related to their performance on a nonverbal associative learning task (Conditional Associative Learning—Levine, Stuss, & Milberg, 1997), providing empirical evidence for an associative learning link to contingency learning in aging research in keeping with the link evidenced in studies with young adults (e.g., Dickinson & Shanks, 1985).

#### Age and Processing Speed

Salthouse (1994b) has suggested that slower processing speed in older adults is a key contributor to age-related decline in associative learning. Speed of processing refers to the swiftness with which cognitive operations are performed (Salthouse, 1996) and is generally measured in terms of the speed of executing elementary operations, including encoding, elaboration, search, rehearsal, retrieval, integration, or abstraction of information accessible in working memory (Lindenberger, Mayr, & Kliegl, 1993). Importantly, because the success of these operations depends on the information available in working memory, if the information is displaced or decays more quickly over time the operations will be less effective (Salthouse, 1996).

In fact, numerous studies have documented a negative relationship between age and performance on a wide range of information-processing tasks (e.g., Cunningham,

1989; Hertzog, 1989; Lindenberger et al., 1993; Salthouse, 1996), and perceptual slowing is widely cited as a main reason for this age-related decline (Lindenberger et al., 1993; Salthouse, 1996). For example, Salthouse (1994b) found that increased age was associated with slower encoding and response processes on the digit-symbol test of perceptual speed, as well as with slower search of the code table and longer time to decide to search the code table. Birren (1965, as cited in Birren, 1974) demonstrated a link between speed and memory when he found intercorrelations between speed and memory measures increased with older adults. For young adults, the correlation between the Wechsler Memory Scale and speed of copying digits was not significantly different from zero (-.01), whereas for older adults a significant correlation of .52 was obtained. Bryan and Luszcz (1996) found that scores on a measure of processing speed mediated age-related variance in a working memory task, indicating speed as a limit to cognitive capacities such as working memory.

Still other studies have shown a reduction in the correlation between age and ability on many cognitive tasks after statistically controlling for speed (e.g., Lindenberger et al., 1993). In addition, age-related influences on many cognitive measures are attenuated after controlling for measures of speed (e.g., Salthouse, 1996; Lindenberger et al., 1993). For example, Schaie (1990) found that age-ability correlations on measures of verbal comprehension, spatial orientation, inductive reasoning, number, and word fluency were reduced after controlling for differences in speed. Similarly, Hertzog (1989) found a significant negative linear age trend for all measured intellectual abilities, of which only one to three percent of the total variance was explainable by linear and quadratic trends of age after controlling for speed. For most measures, commonality analyses

demonstrated substantial age-related variance associated with speed (e.g., 86% in spatial relations; 89% in induction). Similarly, Salthouse (1993b) found variance associated with age in a wide range of cognitive variables was reduced from a mean of 16.2% to 3.6% when measures of processing speed were held constant. Thus, processing speed may be seen as a key age-associated process, both affecting and constraining cognitive abilities (e.g., Salthouse & Babcock, 1991; Lindenberger et al., 1993).

However, processing speed is but one element of an intricate system of cognitive structures (Kail & Salthouse, 1994), and some researchers therefore caution against its portrayal as the ultimate source of cognitive aging (e.g., Lindenberger et al., 1993). For example, potential mediators of the age-cognition relationship include reduced attention (e.g., Stanken, 1988, as cited in Salthouse, 1994a), failure of inhibition (e.g., Hasher & Zacks, 1988, as cited in Salthouse, 1994a), and working memory capacity (e.g., Lindenberger et al., 1993; Salthouse & Babcock, 1991). Regardless of other potential age-related mediators, processing speed has, nonetheless, shown unique and widespread influence on cognitive tasks and therefore warrants further consideration.

#### Processing Speed and Associative Learning

Associative learning is one cognitive ability empirically proven to be negatively impacted by slower processing speed. For example, while studying individual differences in young adults, Kyllonen, Tirre, and Christal (1991), found that speed of memory search predicted associative learning with a short study time (i.e., .5 sec, 1 sec) and that the relationship was attenuated when study time increased (i.e., 4 sec, 8 sec). Moreover, Fisk and Warr (1996) found that age-related variance in their associative learning task was reduced by 75% when controlling for the effects of perceptual speed. Similarly, Salthouse

(1994b) found that the influence of age on associative memory was particularly accounted for by variance due to processing speed for shorter stimulus presentation times. To explain this finding, he concluded that speed is a mediator between age and associative memory, in that increased age is related to slower processing speed which is in turn related to less accurate associative memory.

Based on his findings, Salthouse (1994b) began to theorize as to why processing speed might impact associative learning. He suggested that slower processing might have resulted in insufficient encoding, leading to failure to retain the information between presentations or trials and thus to less accurate associative learning. More specifically, Salthouse (1996) proposed that processing speed impacts associative learning by influencing two fundamental cognitive resources: (1) the amount of *time needed* to perform cognitive operations and (2) the capacity to *coordinate* different sources of information. Salthouse termed the operations impacting these resources the *limited time* and *simultaneity* mechanisms of processing speed. These mechanisms essentially imply that, if information is not simultaneously available in working memory within certain time constraints, associative learning will be negatively impacted.

To clarify further, the limited time mechanism specifies that if information is not fully processed within a limited amount of time, relevant cognitive operations will be incomplete. Thus, in order to effectively encode two stimuli together in working memory, a person must have enough time to fully process the first stimulus before a second occurs. Otherwise, encoded information from the first will be fragile and the association with the second poorly constructed. Salthouse (1996) compared the limited time mechanism to an assembly line—if component parts of a task are not fully processed, later operations can

only be partially completed, and the final products will be impaired. Faster processing speed means *less time* is needed to complete cognitive operations, so slower processors need more time to complete a task as well as faster processors. In this sense, reducing the time constraints for a cognitive task should lead to less disparity in performance between fast and slow processors. Accordingly, the limited time mechanism is relevant primarily when there are restrictions on time available for processing, such as external time limits or concurrent demands on processing (Salthouse, 1996).

Several studies have confirmed the role of the limited time mechanism in older adults by showing that reducing time constraints also reduces age differences in cognitive task performance (e.g., Canestrari, 1963; Monge & Hultsch, 1971). For example, in one of the earliest studies published on the effects of aging and speed on intelligence, Lorge (1936, as cited in Cunningham, 1989) administered three intelligence tests with varied speed demands and found that the highly speeded test produced more pronounced age differences than the least speeded test with liberal time limits. He interpreted these results as demonstrating that the observed age-induced perceptual slowing simply meant more time was needed to perform the necessary information-processing steps, leading to the apparent performance deficit in speeded measures. Concordantly, perception studies (e.g., Kline, 1972, as cited in Birren, 1974) have shown that older adults needed longer stimulus presentation times in order for the initial or target stimulus to even be perceived.

Even though allowing additional time to process information can help older adults' performance on many cognitive tasks, the precise impact on processing speed is not always fully evident with the alleviation of time constraints. Rate of processing also affects the *quality* of the subsuming operations (Salthouse, 1994a). Birren (1974) likened

perceptual slowing to an electrical brown-out, during which many electrical appliances in the home run more slowly as a result of a voltage drop. Like the encumbrance of electrical activities in the home, central cognitive slowing results in slowed behavior. But slowness itself would not be the only deficit—the appliances' functions would also be inadequate. In cognition, slowing affects functions such as perception, encoding, and retrieval from long-term memory, contributing to a decreased likelihood of novel associations (Birren, 1974). Further, because associative learning requires that stimuli are simultaneously available in working memory (Salthouse, 1996), processing information slowly can lead to less information taken in and effectively synchronized at one time.

Salthouse (1996) called the ability to coordinate the necessary components of an operation the *simultaneity mechanism*. Faster synchronization allows better quality of the resulting operation because more information can be processed in a shorter amount of time, which in turn allows more information to be simultaneously represented and enriched for subsequent, higher level processing. Faster processing also permits more rehearsal, so that information from earlier events may be more repeatedly cycled in working memory and thus remain available concurrently with new information presented later in time. Conversely, slower processing could mean information is more easily lost (Myerson et. al., 1990), particularly if events are spread out in time. Salthouse (1996) likened the simultaneity mechanism to juggling. As with any other complex activity, juggling requires the harmonization of constituent tasks—the faster one can “juggle” the many parts of a single task, the better synchronized these parts will be. Taken in light of the earlier assembly line analogy, the simultaneity mechanism could be also viewed as the ability to add additional useful pieces to an item during its time at an assembly

station, where every subsequent station adds more substance, and the final product is strengthened accordingly.

There is empirical evidence that slower processing does indeed impact the quality, not just the speed, of resulting cognitive performance. For example, Rabinowitz (1989) found that, when young and older adults were given unlimited time to study a list of words, free recall performance in both age groups improved compared to a timed condition, but the young adults' improvement was greater than that of the older adults. Rabinowitz suggested that older adults may have used less optimal elaborative memory strategies or may have used their strategies less efficiently than younger adults. Bryan and Luszcz (1996) found that, compared to older adults, young adults showed differentially greater recall of words after three rehearsals than one, showing that additional time did not help older adults perform comparably to younger adults. Moreover, the relationship between age and free recall was mediated by task-independent processing speed. Salthouse (1994b) found older adults made less accurate decisions and took more time to reach and communicate the decisions on computer associative learning tasks, even when they were given no time restrictions and accuracy was emphasized. Based on these findings, Salthouse suggested that the older adults had weaker representations of the stimuli to be learned, because slower processing impeded rehearsal and caused less effective encoding or elaboration. Salthouse (1991) found similar results in many measures, such that substantial age-related differences persisted even when external time limits were removed.

### Processing Speed and Contingency Learning

The link between processing speed and associative learning may also be extended to contingency learning, as processing speed impacts associative learning, which in turn affects contingency learning. There are few studies directly examining a connection between processing speed and contingency learning, yet considerable evidence supports the theory that the ability to quickly process events aids the learning of a contingency between these events. Specifically, studies have found that older and younger adults are affected differentially by altering the timing characteristics in contingency judgment tasks, suggesting that the differences are largely due to slower processing speed in the older adults (e.g., Mercier & Parr, 1996). Other studies, while not implicating processing speed directly, provide additional evidence for the effects of event timing on contingency learning, showing that increased time constraints can reduce contingency judgment accuracy, even in young adults (e.g., Shanks & Dickinson, 1991; Shanks et al., 1989).

For example, Mercier and Parr (1996) attempted to stress the processing efficiency of their young adult participants by forcing the cognitive processes involved in acquiring and maintaining contingency information to operate faster. They manipulated stimulus duration (50 or 200 ms) and intertrial interval (ITI; 50, 200, or 1000 ms) and examined participants' estimates of positive, negative, and zero contingencies (+50, -50, and 0). They used a contingency task in which participants were asked to judge the efficacy of a tank's camouflage by watching as camouflaged and un-camouflaged tanks either exploded or did not explode when entering a field with visually guided landmines. The results confirmed that the participants could discriminate contingencies, although they underestimated the absolute value of negative contingencies slightly more than

positive contingencies. Additionally, time pressure from shorter stimulus durations and shorter ITIs markedly decreased accuracy of the judgments.

Parr and Mercier (1998, Experiment 1) extended these findings by stressing the processing abilities of both older and young adult groups with constrained contingency judgment task timing characteristics. Using a similar video game task, they asked participants to judge the relative efficacy of tank camouflage in protecting against explosion from visually guided mines. They again manipulated stimulus duration (100 or 300 ms) and ITIs (100, 300, or 1000 ms), and they examined weak to strong positive contingencies (.27, .50, or .80). The results showed that increased time constraints (i.e., shorter stimulus duration and ITI) reduced contingency judgment accuracy for both young and older adults, although the detriment was greater for older adults' judgments. Beyond this, increasing the ITI (Experiment 1) reduced age differences—although older adults were less accurate than younger adults at the short (100 ms) ITI, there were no significant age differences at the longer ITIs (300 and 1000 ms).

Mutter and Williams (2004) also attempted to find reduced age differences in contingency learning, by providing additional processing time and more learning trials. Using a variant of a task designed by Hammond (1980) and used in several young adult contingency learning studies (e.g., Dickinson & Shanks, 1985; Wasserman et al. 1983; Chatlosh et al., 1985), they asked older and younger adults to determine the relationship between pressing a response key (R) and the outcome (O) of a flashing triangle. The accuracy of their R-O contingency estimates was examined after three learning conditions: 60 learning trials with a maximum 1-second R-O interval (SI-60), 60 learning trials with a maximum 4-second R-O interval (LI-60), and 240 learning trials with a

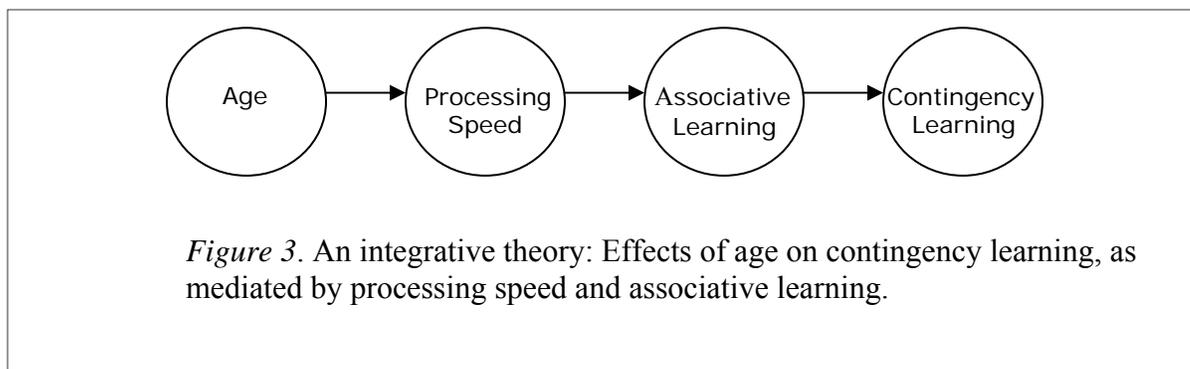
maximum 1-second R-O interval (SI-240). Across conditions, older adults showed poorer discrimination of both positive and negative contingencies than young adults but were especially inaccurate for negative contingencies. Age differences were similar in both the SI-60 and SI-240 conditions, showing that older adults did not differentially benefit from additional learning trials. However, age differences were reduced with a longer R-O interval, although surprisingly not because of improvement in the older adults' judgments. Rather, the accuracy of the young adults' contingency estimates declined with increased sampling time, a finding inconsistent with similar previous studies (i.e., Chatlosh et al., 1995, Experiment 1; Wasserman et al., 1983, Experiment 1). The authors speculated that the task design could have confounded the longer R-O condition, because young participants made substantially more responses when given a longer sampling time. Without cues indicating the beginning and end of these time intervals, it may have been difficult to judge the actual R-O relationships—young adults may have misjudged contingencies simply because they paired temporally contingent events (and non-events) instead of the events that were actually contingent. Thus, even though the results outwardly showed smaller age differences in contingency judgments when participants were given more time to process event information, the limitations of this type of task prevent inferences about the impact of reducing processing time constraints. Therefore, in order to more closely examine the effects of age and processing time on contingency judgment accuracy, there is a need for research that allows more experimental control of the R-O interval across a range of contingency types (i.e., positive, negative, weak, and salient).

### *Current Study*

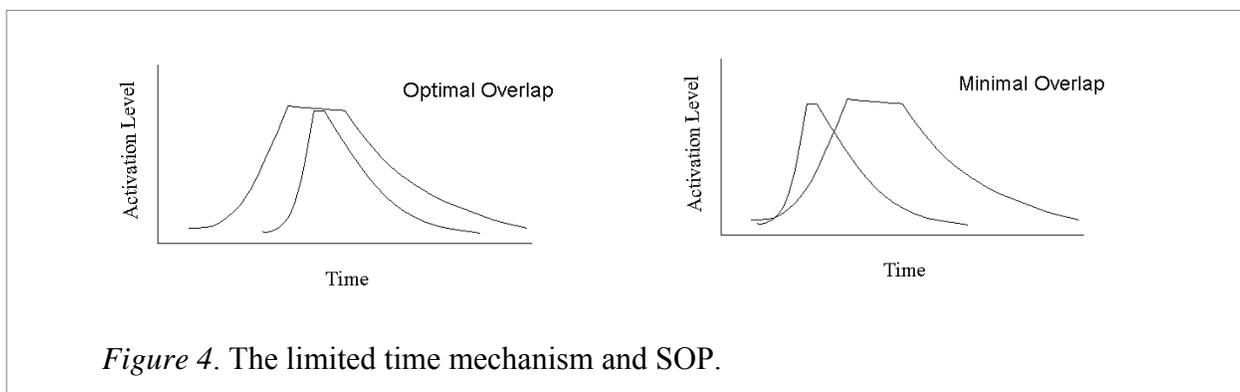
The goal of the current study was to further understand the processes that might impact contingency learning by examining the effects of the limited time and simultaneity mechanisms of processing speed (i.e., Salthouse, 1996) on contingency judgment accuracy. The current study also sought to add more control to the R-O contingency judgment task as well as to examine a range of contingency problem types.

#### Processing Speed Mechanisms and SOP

The hypotheses for this study were based on an integration of Salthouse's (1996) processing speed theory and Wagner's (1981) SOP model of associative learning. In seeking to explain what processes affect contingency learning, previous research has supported associative learning theories (e.g., Shanks, 1987), suggesting that hindering associative learning directly impairs contingency learning (e.g., Mutter & Williams, 2004). One way associative learning could be impaired is by slowed processing speed, as processing speed has been shown to be a mediator between age and associative learning (Salthouse, 1994b). Based on this, it is reasonable to hypothesize that slowed processing speed is likewise a determinant of impaired contingency learning (See Figure 3).

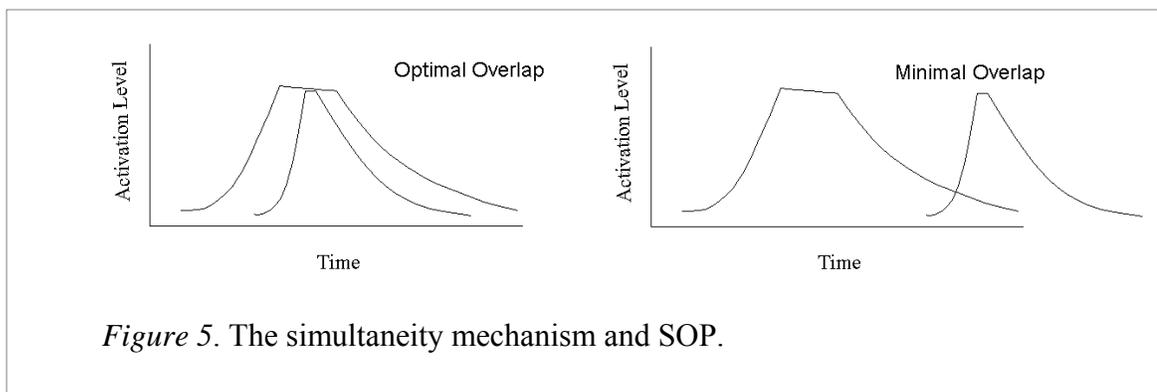


When explaining the limited time mechanism, Salthouse (1996) stated that there must be sufficient time for the first stimulus to be processed before the second occurs, or the relevant operations will not be successfully executed. Likewise, Wagner (1981) posited that the best associative learning occurs if the A1 activation states for both events overlap at their highest peaks. Thus, by this view the most optimal associative learning situation exists when a person has had enough time to process the first stimulus by the time the second occurs. Conversely, if the outcome event occurs before one has had time to fully process the first event, A1 overlap will be lower, and the degree of association will be little to none (see Figure 4).



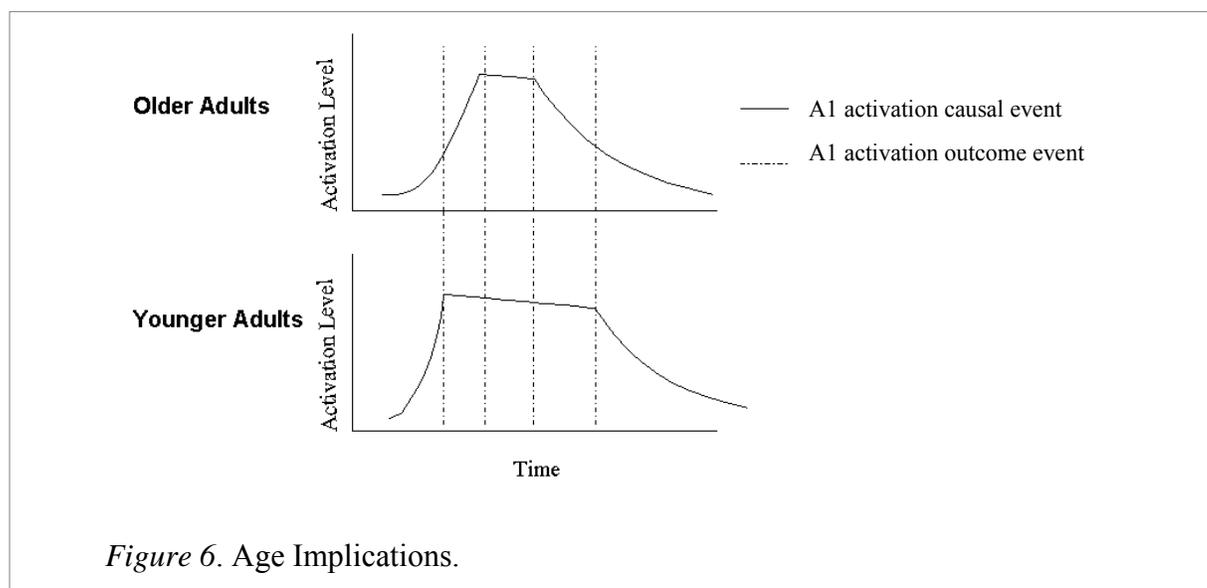
In SOP terms, the simultaneity mechanism involves the ability to coordinate, or ‘juggle,’ the A1 activation states for multiple events. In other words, the A1 activation states for the events must, again, overlap in order for the association to be made, and the simultaneity mechanism involves how well one is able to keep the event representations active in working memory over time in order to associate them. One way to maintain A1 activation is through rehearsal. The optimal learning situation, in regards to the simultaneity mechanism, would be one in which there is little need for rehearsal, because the A1 states of both events occur simultaneously. This is the case when an outcome

immediately follows a response. Importantly, the first event should also be fully activated before the second occurs (limited time mechanism). A less optimal condition involves the outcome event occurrence some time after the first event. In order for the A1 representations to occur simultaneously, the A1 for the first event must be maintained through rehearsal (see Figure 5).



The actual interval between response and outcome could lead to different overlaps in A1 activation states for different people, depending on their processing speed limitations. In other words, the exact moment in time an event occurs in the environment is not necessarily the same moment the event is represented in working memory—there is a period of time before a stimulus' A1 activation reaches peak, and this latency varies among individuals depending on their processing speed. Thus, consistent timing of external events can still lead to inconsistent performance between individuals, because different people process information at different rates. Moreover, as mentioned previously, both speed of activation in memory and quality of learned association can be affected. In a basic sense then, one's internal processing capability should be optimally matched to the external timing of events in order for associative learning to be at its best. What this means is that, if environmental events occur more quickly than they can be

processed, or if events do not occur close enough together in time, associative learning will be impaired. Because increased age is related to slower processing, reducing the time to process co-occurring events should cause especially poor associative learning for older adults. Similarly, requiring extra rehearsal in order to keep co-occurring events in a state of simultaneous activation should be more difficult for older adults and impair associative learning (see Figure 6).



### Task Timing Manipulations and Contingency Judgment

The current study investigated the impact of processing speed on young and older adults' R-O contingency judgment by manipulating timing characteristics of a contingency judgment task. In a specific attempt to correct for the limitations present in Mutter and Williams' (2004) study, the beginning and end of each trial were clearly delineated, and young and older participants were required to respond (or not respond) only once within both short and long sampling periods. In order to test the limited time mechanism, the amount of time available to generate a response ( $T_G$ ) was varied. It was

hypothesized that individuals with slower processing speed would be taxed with a short  $T_G$  but fully able to process the first event with a longer  $T_G$ . In order to test the simultaneity mechanism, the length of time the representation of the first event must be held in memory ( $T_M$ ) was manipulated by varying the interval between the response and outcome. It was hypothesized that a long interval required greater rehearsal of the representation of the first event to maintain a state of A1 memory activation until the outcome event occurred. Thus, individuals with slower processing speed should have more difficulty maintaining an A1 state of activation for the response in a long R-O interval but should have a high A1 state of activation for the response in a short R-O interval. The various combinations of the short and long timings composed four conditions:  $T_G$ -Short/ $T_M$ -Short (SS),  $T_G$ -Short/ $T_M$ -Long (SL),  $T_G$ -Long/ $T_M$ -Short (LS), and  $T_G$ -Long/ $T_M$ -Long (LL) (See Figure 7).

		$T_G$	
		Short	Long
$T_M$	Short (Delay)	SS	LS
	Long (Trace)	SL	LL

*Figure 7.* Experimental Conditions.

Compared to young adults, it was expected that older adults would make less accurate contingency judgments overall, especially for negative contingencies (cf. Mutter & Williams, 2004). It was specifically expected that older adults would show differential impairment from an increased impact of the limited time and simultaneity mechanisms

for event pairs, compared to young adults. Beyond this, it was hypothesized that contingency judgments would be less accurate in the less optimal short generation time ( $T_G$ ) and long memory time ( $T_M$ ) conditions than in the long  $T_G$  and short  $T_M$  conditions. Furthermore, it was expected that contingency judgments would be least accurate in the  $T_G$ -short/ $T_M$ -long (SL) condition and most accurate in the  $T_G$ -long/ $T_M$ -short (LS) condition. Finally, age differences were expected to be magnified in these non-optimal timing conditions.

## Chapter Three

### Method

#### Participants

Forty-eight young (39 female) adults, ages 18-26 ( $M = 19.9$ ;  $SD = 1.86$ ), and 48 older adults (33 female), ages 61-91 ( $M = 70.6$ ;  $SD = 7.45$ ) participated in this study. Four additional participants served as pilot subjects (1 older). Two older participants were excluded from analyses due to failure to comply with experiment instructions, and one younger participant did not finish the task due to scheduling difficulties. Young adults were recruited from introductory psychology classes and received course credit and a small monetary stipend for their participation. Older adults were recruited from the community via mass mailings and advertisements and were paid a monetary stipend for their participation. Biographical data (age, race, gender, socioeconomic status, years of education, and marital status), as well as measures of basic health and cognitive ability (verbal knowledge, verbal fluency, perceptual speed, working memory executive functioning, and associative learning) were collected for both groups. Participants who reported current use of medications known to affect cognitive ability or who suffered from neurological or psychological impairment were excluded from the study. All participants were reportedly in good health for their age group.

#### Design and Materials

A 2 (Age: Young vs. Older) x 2 (Generation Time  $T_G$ : 750 ms vs. 2250 ms) x 2 (Memory Time  $T_M$ : 1000 ms vs. 4000 ms) x 9 (Contingency: .875/.875, .875/.50,

.875/.125, .50/.50, .50/.125, .50/.875, .125/.125, .125/.875, .125/.50) mixed factorial design with repeated measures on contingency was used.

The generation of the response ( $T_G$ ) occurred within either a 750 or 2250 ms period (see Appendix B). The short time was based on an associative learning study by Salthouse (1994b), in which he found young adults learned associations at close to 90 percent correct at a 750 ms stimulus presentation time, and their learning remained maximized at this level, even with greater stimulus presentation time (1000 ms). Older adults' associative learning was only close to 70 percent at the 750 ms stimulus presentation time and continued to rise, nearing 75 percent at 1000 ms. Salthouse (1994b) suggested that "the average adult over age 60 would not be able to engage in more extensive processing with stimulus presentation times of less than 1000 ms" (p. 1502). When given no time constraints, older adults self-paced an average of 1500 ms per stimulus presentation (Salthouse, 1994b). Based on Salthouse's (1994b) study, the current study sought to provide sufficient processing time for both young and older adults by raising the longer response generation time to 2250 ms.

The outcome ( $T_M$ ) occurred either immediately (1000 ms) or after 4000 ms. The short  $T_M$  condition supposedly created little need for rehearsal, regardless of processing speed. The long  $T_M$  condition was patterned after that of Mutter and Williams (2004) and was expected to be a sufficient amount of time for fast processors to maintain the memory representation of the first stimulus but problematic for slower processors. The outcome occurred for 500 ms in all conditions. The inter-trial interval was fixed at 1000 ms, to promote processing of the outcome event before the next trial began.

Contingency problems were administered in an order determined by a software randomization routine. Because outcome probability has been found to produce overestimation of contingency judgments in younger adults (e.g., Allan & Jenkins, 1980; Jenkins & Ward, 1965), the contingency design was fully balanced with the three conditional probabilities (see Appendix A). The contingency for each problem was computed using the formula  $\Delta = P(\text{Outcome/Response}) - P(\text{Outcome}/\sim\text{Response})$ . Values of  $P(O/R)$  and  $P(O/\sim R)$  were .125, .500, and .875, and problem contingencies were created by combining the values of these probabilities (e.g., .125/.875, etc.). Thus, participants judged nine problems, with three non-contingencies, one positive and one negative strong contingency (0.75), and two positive and two negative weak contingencies (0.375).

### Procedure

Participants were tested individually in two sessions on different days lasting approximately two hours each, with breaks given halfway through each session and as needed. All testing was conducted in the Cognition Laboratory or similar experimental room. Some tasks were completed on a Macintosh computer and some using a pencil and paper.

Participants first completed an informed consent form and a demographic and health questionnaire. Before any testing began, participants were given an opportunity to ask questions or voice concerns. They then completed the experimental task and several measures from a larger protocol that assesses general cognitive ability. These tests included standardized and unstandardized measures of processing speed [i.e., Pattern Comparison (Salthouse, 1994a); WAIS-III Digit Symbol (Wechsler, 1997)], associative

learning [i.e., Conditional Associative Learning (e.g., Levine, Stuss, & Milberg, 1997; Salthouse, 1994b)], working memory executive functioning [i.e., Reading Span (Salthouse & Babcock, 1991)], and verbal knowledge [i.e., Mill Hill Vocabulary, WAIS-III Information (Wechsler, 1997)].

The experimental task was run on a Macintosh PowerPC. Participants were first shown the experiment instructions. These instructions directed them to determine whether pressing the spacebar on the computer keyboard (response) had any effect on whether a triangle flashed (outcome). They were told that, in order to learn the relationship, they must sometimes press the spacebar and sometimes not press the spacebar (See Appendix A). After reading the instructions, any questions were answered, and a set of 10 practice trials began, programmed with a noncontingent relationship with two conditional probabilities equal to .500. Participants saw a white background screen and a black outline of an equilateral triangle with 1-inch sides. At the beginning of each trial, the generation time period ( $T_G$ ) was signaled by a small row of boxes on the bottom of the screen, which emptied sequentially until the generation time ran out. Participants were instructed that they must choose to press or not press the spacebar during this period of time. Then there was a period of memory time ( $T_M$ ), after which the triangle either flashed, from white to black to white, or did not flash at all. If a response was made during the generation time, the outcome occurred based on the programmed contingency according to  $P(O/R)$ ; if a response was not made, the outcome occurred based on the programmed contingency according to  $P(O/\sim R)$ . One second later, a new trial began.

After 60 trials, participants were asked to estimate the contingency between the button press and the triangle flash. Contingency judgments were made by typing in a

number from  $-100$  to  $+100$ . The numerical end- and midpoints of the scale were marked with such verbal indicators of the strength of the relationships as “strongly causes,” “strongly prevents,” and “no relationship.” Thus, a perfect positive contingency was denoted as  $+100$  (i.e., pressing the response key always caused the triangle to flash), a perfect negative contingency as  $-100$  (i.e., pressing the key always prevented the triangle from flashing), and a non-contingent relationship as  $0$  (i.e., there was no relationship between the response and outcome events).

After estimating the overall contingency, participants were instructed to make conditional probability estimates of the relationship between pressing or not pressing the button press and the triangle flashing. They first estimated the probability that the triangle would flash when the key was pressed and then judged the probability that the triangle would flash when the key was not pressed. To respond, they typed their choice ranging from  $0\%$  to  $100\%$ , with  $100\%$  indicating that the triangle would always flash,  $0\%$  indicating that the triangle definitely would not flash, and  $50\%$  indicating that the triangle would flash about half the time when the key was pressed and about half the time when it was not pressed. After making their judgments, participants began the next contingency problem.

After completing the second session, participants were debriefed, given the opportunity to ask questions, and compensated for their time.

## Chapter Four

### Results

#### Participant Characteristics

To ensure that age differences in basic cognitive ability were consistent across conditions, a 2 (Age) x 2 ( $T_G$ ) x 2 ( $T_M$ ) MANOVA was conducted for the measures of processing speed, working memory executive functioning, associative learning, and verbal knowledge. Age was the only significant effect in this analysis [Age,  $F(6, 61) = 19.69$ ,  $\eta^2 = .66$ ;  $T_G$ ,  $F(6, 61) < 1$ ,  $\eta^2 = .04$ ;  $T_M$ ,  $F(6, 61) < 1$ ,  $\eta^2 = .03$ ; Age x  $T_G$ ,  $F(6, 61) = 1.24$ ,  $\eta^2 = .11$ ; Age x  $T_M$ ,  $F(6, 61) < 1$ ,  $\eta^2 = .04$ ; Age x  $T_G$  x  $T_M$ ,  $F(6, 61) < 1$ ,  $\eta^2 = .01$ ]. Follow-up univariate tests were conducted for these age differences, collapsed across condition. These data are shown in Table 1. Young adults scored higher than older adults on measures of processing speed, WM executive functioning, and associative learning. Older adults scored higher than young adults on measures of verbal knowledge. Thus, age differences in these basic cognitive abilities followed the typical pattern shown in the cognitive aging literature (see Mutter & Williams, 2004).

Table 1

*Participant Characteristics for Young and Older Adults*

	Young	Older
Processing Speed		
Digit Symbol*	84.11 (2.47)	61.90 (2.34)
Pattern Comparison*	56.91 (1.54)	43.82 (1.46)
WM Executive Function		
Reading Span*	2.71 (.19)	2.05 (.18)
Associative Learning		
CAL Retained Response*	23.57 (1.55)	15.36 (1.47)
Verbal Knowledge		
Mill Hill Vocabulary*	29.89 (1.25)	38.36 (1.19)
WAIS-III Information*	15.06 (.93)	18.10 (.88)

\*Age difference is significant at  $p \leq .05$  or better.

Analyses

Data were collected for nine contingency problems constructed from an orthogonal combination of three levels of conditional probability: .875, .500, and .125. These nine contingency problems measured five different contingencies (-.75, -.375, 0, .375, and .75), so the data for three problem-types (-.375, 0, and .375) were collapsed across contingency. Three primary dependent measures were collected or calculated for each of the five levels of programmed contingency. Of primary interest were the direct

contingency judgments given by participants (divided by 100). Second, the error associated with each judgment was obtained by finding the absolute difference between these judgments and the programmed contingencies:  $JE = |C_{est} - C_{prog}|$ . Third, derived contingency judgment scores were obtained for each contingency problem by subtracting the conditional probability estimates given by participants:  $\Delta P = P(O/R) - P(O/\sim R)$ . Outliers and missing data for contingency and conditional probability judgments for the nine problems were replaced by linear trend imputation after breaking the data into separate files by age group and condition. Overall, less than 5 percent (4.5%) of the data was altered by this method. A 2 (Age: young vs. older) x 2 (Generation Time ( $T_G$ ): short vs. long) x 2 (Memory Time ( $T_M$ ): short vs. long) x 5 (Contingency: -.75, -.375, 0, .375, .75) mixed-factorial analyses of variance (ANOVA) was conducted for judgment error and direct and derived contingency judgments. Trend analyses for the reliable main and interaction effects of contingency were also conducted for direct and derived contingency judgments. A criterion value of  $p \leq .05$  was used for all analyses, unless otherwise indicated.

### Response Probability

Constraining the time interval during which participants could make a response ( $T_G$ ) was intended to limit over-responding during the longer R-O interval conditions in order to provide a more effective test of the effects of a short versus long time to process a causal event. However, it is possible that, due to age-related changes in motor responding, some older adults in the short  $T_G$  condition were less able to generate a response and thus less effectively sampled  $P(O/R)$ . To evaluate motor response patterns for both age groups in all conditions, the probability of responding was calculated for

each contingency problem for each participant (total number of responses made / 60 total trials), and these data were submitted to a 2 (Age) x 2 ( $T_M$ ) x 2 ( $T_G$ ) x 5 (Contingency Problem) mixed-factorial ANOVA. No significant effects were found [Contingency,  $F(4, 352) = 1.65$ ,  $MSE = .01$ ,  $\eta^2 = .02$ ; Age x Contingency,  $F(4, 352) = 1.99$ ,  $MSE = .01$ ,  $\eta^2 = .02$ ; Age x  $T_M$ ,  $F(1, 88) = 2.06$ ,  $MSE = .11$ ,  $\eta^2 = .02$ ;  $T_G$  x  $T_M$  x Contingency,  $F(4, 352) = 1.95$ ,  $MSE = .01$ ,  $\eta^2 = .02$ ; Age x  $T_G$  x  $T_M$  x Contingency,  $F(4, 352) = 1.52$ ,  $MSE = .01$ ,  $\eta^2 = .02$ ; all others,  $F < 1$ ]. Thus, there was no difference in response probability for young and older adults for either the short or long generation time ( $T_G$ ) conditions.

#### Direct Contingency Judgments

Figure 8 shows participants' direct contingency judgments in the four timing conditions at each level of programmed contingency. As depicted, young and older participants were able to discriminate the five contingencies,  $F(4, 352) = 144.36$ ,  $MSE = .11$ ,  $\eta^2 = .62$ . The linear trend of this reliable main effect of contingency was significant,  $F(1, 88) = 254.61$ ,  $MSE = .26$ ,  $\eta^2 = .74$ , showing that participants judged contingencies much like the nominal programmed contingencies. However, even though participants across both age groups discriminated the contingencies, significant age differences were found in this ability,  $F(1, 88) = 8.65$ ,  $MSE = .12$ ,  $\eta^2 = .09$ , with older adults' overall judgments more positive than young adults' judgments. Moreover, this main effect of age was qualified by a significant Age x Contingency interaction,  $F(4, 352) = 5.03$ ,  $MSE = .11$ ,  $\eta^2 = .05$ . The linear trend for this interaction was also significant,  $F(1, 88) = 8.75$ ,  $MSE = .26$ ,  $\eta^2 = .09$ , confirming that the slope of the contingency judgment function was steeper for young adults than for older adults. Subsequent tests of simple effects revealed that, in particular, older adults gave higher judgments for the negative contingencies

( $-.75$ ,  $M = -.28$ ,  $SE = .07$ ;  $-.375$ ,  $M = -.01$ ,  $SE = .04$ ) and zero contingency ( $M = .10$ ,  $SE = .03$ ) than did young adults ( $-.75$ ,  $M = -.57$ ,  $SE = .07$ ;  $-.375$ ,  $M = -.18$ ,  $SE = .04$ ;  $0$ ,  $M = -.02$ ,  $SE = .03$ ) [ $-.75$ ,  $F(1, 94) = 7.99$ ,  $MSE = .25$ ;  $-.375$ ,  $F(1, 94) = 8.42$ ,  $MSE = .08$ ;  $0$ ,  $F(1, 94) = 11.07$ ,  $MSE = .03$ ], whereas both age groups rated the positive contingencies similarly [ $.375$ ,  $F(1, 94) < 1$ ;  $.75$ ,  $F(1, 94) = 1.09$ ,  $MSE = .18$ ].

Direct contingency judgments were also affected by task timing conditions. There was no main effect of generation time ( $T_G$ ),  $F(1, 88) < 1$ ,  $MSE = .12$ ,  $\eta^2 = .15$ , nor any interaction with this timing condition variable alone [ $Age \times T_G$ ,  $F(1, 88) < 1$ ,  $MSE = .12$ ,  $\eta^2 = .01$ ;  $T_G \times CJ$ ,  $F(4, 352) < 1$ ,  $MSE = .12$ ,  $\eta^2 = .01$ ;  $T_G \times T_M$ ,  $F(1, 88) = 3.24$ ,  $MSE = .12$ ,  $\eta^2 = .04$ ,  $p = .08$ ;  $Age \times T_G \times CJ$ ,  $F(4, 352) < 1$ ,  $MSE = .11$ ,  $\eta^2 = .01$ ]. However, the  $Age \times T_G \times T_M$  interaction was significant,  $F(1, 88) = 5.32$ ,  $MSE = .12$ ,  $\eta^2 = .06$ . To examine this interaction further, tests of simple interactions were conducted for each age group. Young adults showed no significant effect of  $T_G \times T_M$  condition,  $F(1, 88) < 1$ . Instead, the  $Age \times T_G \times T_M$  interaction was driven by the significant  $T_G \times T_M$  interaction for the older adults,  $F(1, 88) = 8.46$ ,  $MSE = .12$ . Tests of simple effects revealed that, for older adults in the  $T_M$ -short condition, judgments were not significantly different for the  $T_G$ -short ( $M = .25$ ,  $SE = .05$ ) than for the  $T_G$ -long condition ( $M = .13$ ,  $SE = .06$ ),  $F(1, 88) = 3.70$ ,  $MSE = .12$ . In contrast, for older adults in the  $T_M$ -long condition, judgments were significantly higher for the  $T_G$ -long ( $M = .18$ ,  $SE = .06$ ) than for the  $T_G$ -short condition ( $M = .04$ ,  $SE = .05$ ),  $F(1, 88) = 4.79$ ,  $MSE = .12$ . Thus, the effects of generation time worked in conjunction with those of temporal contiguity to affect older adults' judgments differently from young adults. Although judgments collapsed across contingency were closer to zero for older adults in the  $T_G$ -short/ $T_M$ -long condition and more positive in the

$T_G$ -short/ $T_M$ -short condition, it is difficult to determine whether these higher average judgments were due to less accurate (and thus more positive) judgments for the negative contingencies or to more accurate (and thus more positive) judgments for the positive contingencies. This effect of condition did not interact with contingency [ $T_G \times T_M \times$  Contingency,  $F(4, 352) = 1.14$ ,  $MSE = .11$ ,  $\eta^2 = .01$ ; Age  $\times T_G \times T_M \times$  Contingency,  $F(4, 352) < 1$ ,  $MSE = .11$ ,  $\eta^2 = .00$ ].

No main effect of temporal contiguity ( $T_M$ ) was observed,  $F(1, 88) = 1.62$ ,  $MSE = .12$ ,  $\eta^2 = .02$ , but this variable interacted with contingency,  $F(4, 352) = 8.45$ ,  $MSE = .11$ ,  $\eta^2 = .09$ . The linear trend of contingency varied for the two levels of  $T_M$ ,  $F(1, 88) = 8.75$ ,  $MSE = .26$ ,  $\eta^2 = .13$ , confirming that the slope of the contingency judgment function was more pronounced for participants in the  $T_M$ -short conditions compared to participants in the  $T_M$ -long conditions. No Age  $\times T_M$  interaction was found,  $F(1, 88) = 1.87$ ,  $MSE = .12$ ,  $\eta^2 = .02$ , but an Age  $\times T_M \times$  Contingency interaction was observed,  $F(4, 352) = 2.55$ ,  $MSE = .11$ ,  $\eta^2 = .03$ , suggesting that the effect of temporal contiguity on contingency judgment varied for young and older adults. The linear trend for this interaction was significant,  $F(1, 88) = 3.91$ ,  $MSE = .26$ ,  $\eta^2 = .04$ . To investigate this interaction further, tests of simple interactions were conducted for each age group. For young adults, the  $T_M \times$  Contingency interaction was significant,  $F(4, 184) = 10.79$ ,  $MSE = .10$ . Tests of simple effects indicated that, for young adults,  $T_M$  had the greatest effect on the strong  $\pm .75$  contingencies. Specifically, young adults in the  $T_M$ -long condition underestimated these contingencies compared to those in the  $T_M$ -short condition [ $-.75$ ,  $F(1, 46) = 13.63$ ,  $MSE = .20$  ( $T_M$ -long,  $M = -.33$ ,  $SE = .09$ ;  $T_M$ -short,  $M = -.81$ ,  $SE = .09$ );  $.75$ ,  $F(1, 46) = 13.11$ ,  $MSE = .11$  ( $T_M$ -long,  $M = .52$ ,  $SE = .09$ ;  $T_M$ -short,  $M = .86$ ,  $SE = .09$ );  $.375$ ,  $F(1, 46) =$

2.93,  $MSE = .06$ ; All other  $F$ 's  $< 1$ ]. In contrast, for older adults, the  $T_M \times$  Contingency interaction was not significant,  $F(4, 184) = 1.18$ ,  $MSE = .12$ , indicating that contingency judgments were similar for older adults given either a short or long R-O interval between events.

To test whether young and older adults' judgments differed from each other given a short or long  $T_M$  condition, tests of Age  $\times$  Contingency simple interactions were conducted for each level of the  $T_M$ . The Age  $\times$  Contingency interaction was significant for the  $T_M$ -short condition,  $F(4, 184) = 10.49$ ,  $MSE = .08$ . Subsequent tests of simple effects revealed age differences for the  $-.75$ ,  $F(1, 46) = 25.83$ ,  $MSE = .11$ ,  $-.375$ ,  $F(1, 46) = 8.60$ ,  $MSE = .08$ ,  $0$ ,  $F(1, 46) = 6.87$ ,  $MSE = .04$ , and  $.75$ ,  $F(1, 46) = 5.56$ ,  $MSE = .09$ , contingency levels [ $.375$ ,  $F(1, 46) < 1$ ]. In contrast, an Age  $\times$  Contingency interaction did not reach significance for the  $T_M$ -long condition,  $F(4, 184) < 1$ . Thus, young and older adults gave different judgments given a short R-O interval, particularly for the negative contingencies ( $-.75$  and  $-.375$ ) and the strong positive contingency ( $.75$ ), with young adults' judgments closer to accurate. Yet these age differences were not found with a long R-O interval.

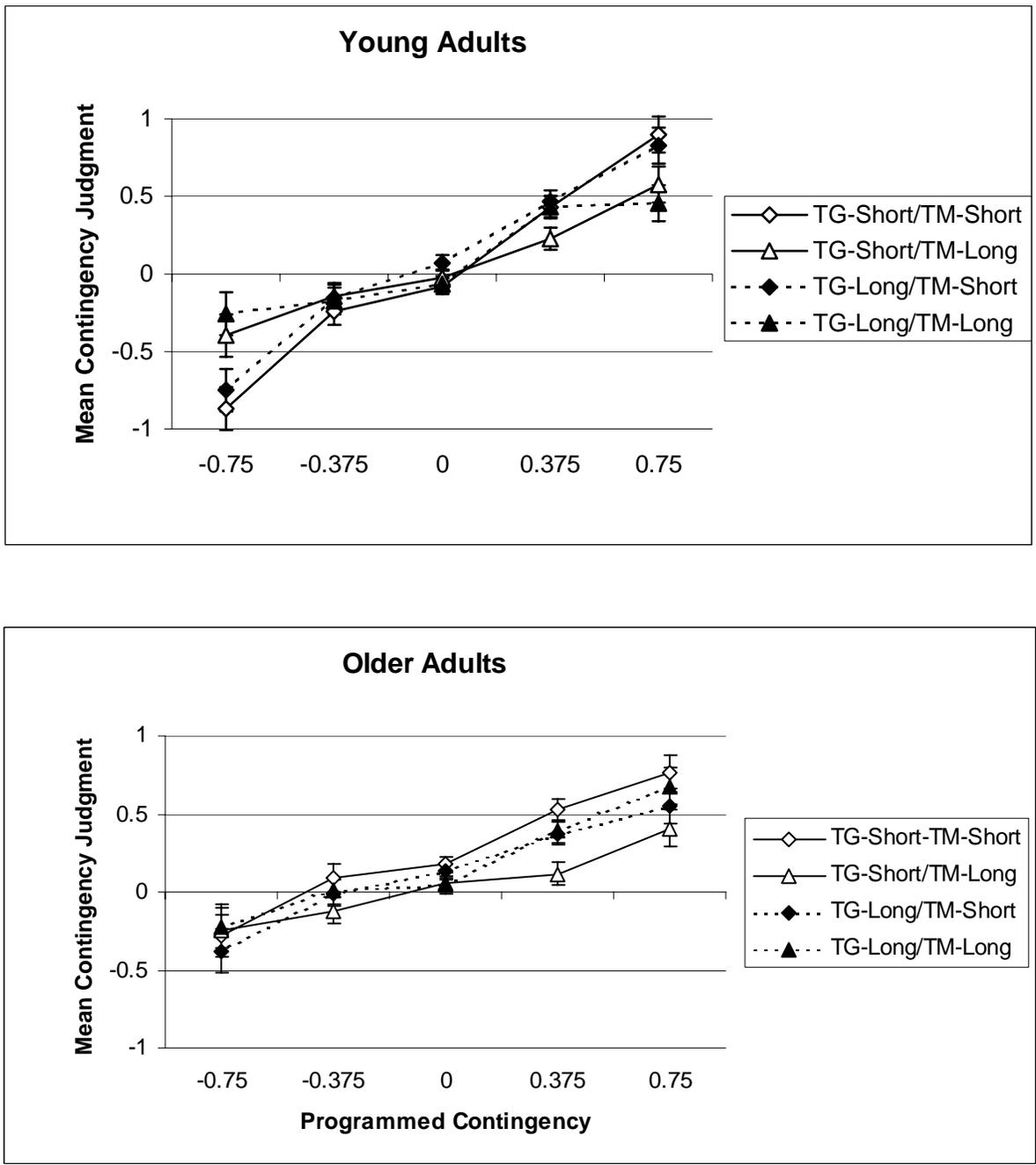


Figure 8. Young and older adults' mean direct contingency judgments by task timing condition as a function of programmed R-O contingency.

### Contingency Judgment Error

Contingency judgment error data are shown in Figure 9. Analyses of these data revealed a significant main effect of contingency,  $F(4, 352) = 13.31$ ,  $MSE = .06$ ,  $\eta^2 = .13$ , showing that participants had greater error for some contingency problems than for others. Furthermore, a main effect of age,  $F(1, 88) = 7.18$ ,  $MSE = .09$ ,  $\eta^2 = .08$ , showed that older adults had greater error in their contingency judgments than young adults. These findings align with those found for direct contingency judgments.

No significant findings were observed for generation time ( $T_G$ ),  $F(1, 88) = 1.06$ ,  $MSE = .09$ ,  $\eta^2 = .01$ , nor for any interactions with  $T_G$  [Age x  $T_G$ ,  $F(1, 88) < 1$ ,  $MSE = .09$ ,  $\eta^2 = .00$ ;  $T_G$  x Contingency,  $F(4, 352) < 1$ ,  $MSE = .06$ ,  $\eta^2 = .01$ ; Age x  $T_G$  x Contingency,  $F(4, 352) < 1$ ,  $MSE = .06$ ,  $\eta^2 = .01$ ;  $T_G$  x  $T_M$ ,  $F(1, 88) < 1$ ,  $MSE = .09$ ,  $\eta^2 = .00$ ; Age x  $T_G$  x  $T_M$ ,  $F(1, 88) < 1$ ,  $MSE = .09$ ,  $\eta^2 = .00$ ;  $T_G$  x  $T_M$  x Contingency,  $F(4, 352) < 1$ ,  $MSE = .06$ ,  $\eta^2 = .01$ ; Age x  $T_G$  x  $T_M$  x Contingency,  $F(4, 352) = 1.46$ ,  $MSE = .06$ ,  $\eta^2 = .02$ ]. Thus, the effect of  $T_G$  x  $T_M$  condition found for older adults' contingency judgments was not corroborated when using absolute deviation (judgment error) scores as the dependent variable.

The main effect of temporal contiguity ( $T_M$ ) was significant,  $F(1, 88) = 6.63$ ,  $MSE = .09$ ,  $\eta^2 = .07$ , but this effect was qualified by an Age x  $T_M$  interaction,  $F(1, 88) = 4.15$ ,  $MSE = .09$ ,  $\eta^2 = .05$ , and a  $T_M$  x Contingency interaction,  $F(4, 352) = 8.28$ ,  $MSE = .06$ ,  $\eta^2 = .09$ . The Age x Contingency interaction was not significant,  $F(4, 352) = 2.05$ ,  $MSE = .06$ ,  $\eta^2 = .02$ ,  $p = .09$ , but there was again a three-way Age x  $T_M$  x Contingency interaction,  $F(4, 352) = 2.05$ ,  $MSE = .06$ ,  $\eta^2 = .04$ .

Follow-up tests of  $T_M \times$  Contingency simple interactions for each age group were conducted to further examine the Age  $\times$   $T_M \times$  Contingency interaction. For young adults, the  $T_M \times$  Contingency interaction was significant,  $F(4, 184) = 15.19$ ,  $MSE = .04$ , and tests of simple effects revealed that judgment error was significantly lower in the short  $T_M$  condition than in the long  $T_M$  condition for all but the weak  $\pm.375$  contingencies [- $.75$ ,  $F(1, 46) = 18.38$ ,  $MSE = .12$ ;  $-.375$ ,  $F(1, 46) < 1$ ,  $MSE = .02$ ;  $0$ ,  $F(1, 46) = 6.22$ ,  $MSE = .04$ ;  $.375$ ,  $F(1, 46) = 3.13$ ,  $MSE = .01$ ;  $.75$ ,  $F(1, 46) = 18.20$ ,  $MSE = .05$ ]. For older adults, the  $T_M \times$  Contingency interaction was not significant,  $F(4, 184) = 1.47$ ,  $MSE = .08$ .

Tests of Age  $\times$  Contingency simple interactions for each  $T_M$  condition revealed age differences for the short  $T_M$  condition,  $F(4, 184) = 6.99$ ,  $MSE = .04$ , but not for the long  $T_M$  condition,  $F(4, 184) < 1$ ,  $MSE = .08$ . Analyses of simple effects revealed that the age differences in the  $T_M$ -short condition were driven in particular by increased error for the older adults in all but the zero contingency problems [- $.75$ ,  $F(1, 46) = 19.14$ ,  $MSE = .07$ ;  $-.375$ ,  $F(1, 46) = 10.09$ ,  $MSE = .04$ ;  $0$ ,  $F(1, 46) = 1.95$ ,  $MSE = .05$ ;  $.375$ ,  $F(1, 46) = 4.56$ ,  $MSE = .02$ ;  $.75$ ,  $F(1, 46) = 4.07$ ,  $MSE = .05$ ]. These findings indicate that the Age  $\times$   $T_M \times$  Contingency interaction found for contingency judgment error was driven by the improvement in young adults' contingency judgments given a shorter R-O interval accompanied by no significant difference in older adults' judgments given a short or long R-O interval. This finding mirrors that found for young and older adults' direct contingency judgments.

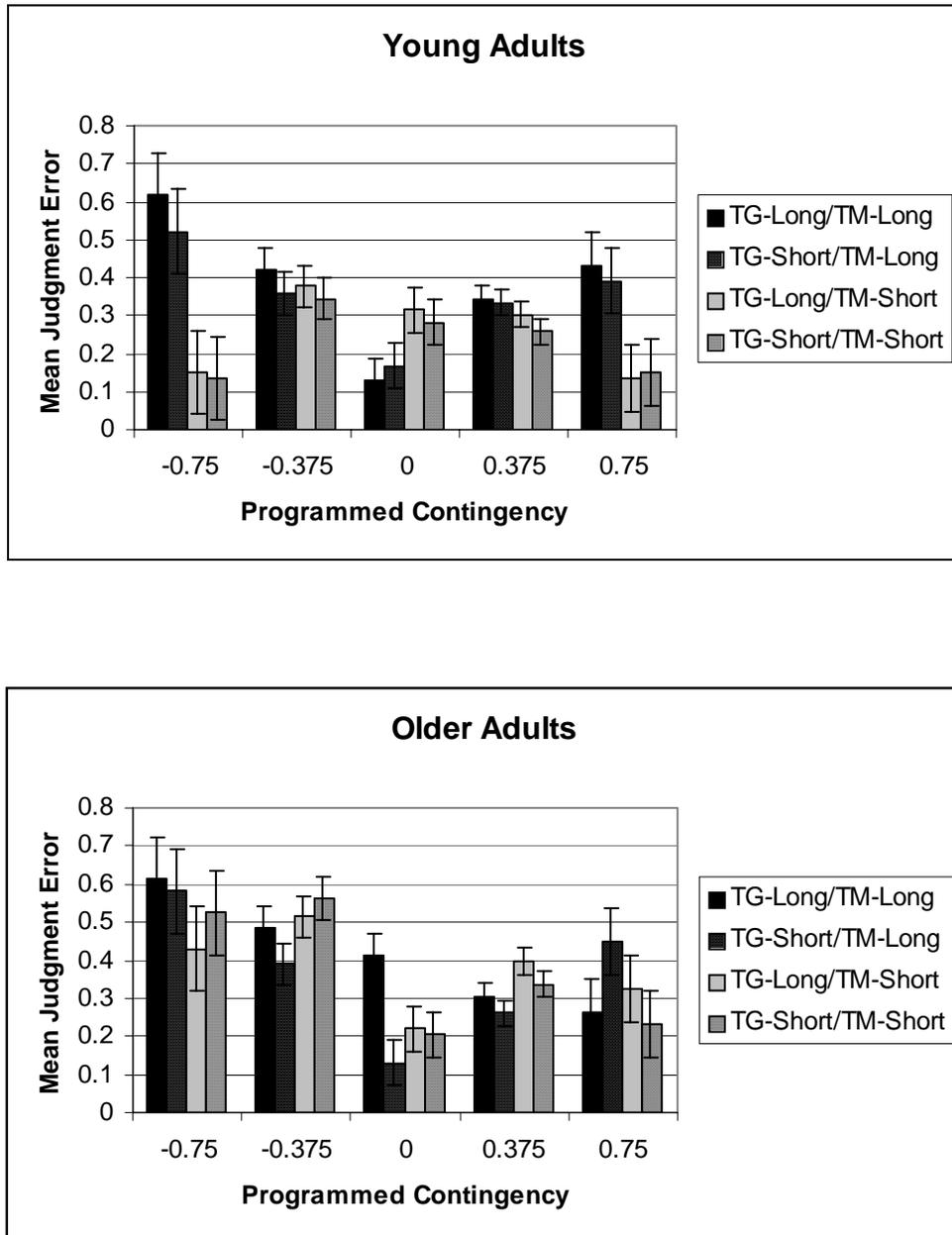


Figure 9. Young and older adults' mean contingency judgment error by condition for each programmed R-O contingency.

### Derived Contingency Judgments

Derived contingency judgment data are depicted in Figure 10. Analyses of these data revealed a main effect of contingency,  $F(4, 352) = 121.71$ ,  $MSE = .09$ ,  $\eta^2 = .58$ . The linear trend of this effect was significant,  $F(1, 88) = 194.60$ ,  $MSE = .21$ ,  $\eta^2 = .69$ , showing that participants across the two age groups gave conditional probability judgments for each contingency problem that increased as a linear function of programmed R-O contingency. In contrast to the previous analyses, no main effect of age was observed,  $F(1, 88) < 1$ ,  $MSE = .06$ ,  $\eta^2 = .00$ , showing that both young ( $M = .01$ ,  $SE = .02$ ) and older ( $M = .00$ ,  $SE = .02$ ) adults' mean derived contingency judgments were highly symmetrical around zero. Therefore, older adults did not show a strong positive bias in contingency judgments when these were derived from their conditional probability judgments. However, age did interact with contingency,  $F(4, 352) = 3.52$ ,  $MSE = .09$ ,  $\eta^2 = .04$ . The linear trend for this interaction was significant,  $F(1, 88) = 5.34$ ,  $MSE = .21$ ,  $\eta^2 = .06$ , showing that the slope of the young adults' derived contingency judgments was steeper than that of the older adults. Notably, both negative and positive derived contingency judgments were closer to zero for older adults than for young adults, suggesting that the difference between the two conditional probability estimates was smaller for older adults than for young adults in the contingent problems.

Age differences were observed for the task timing manipulations as well. No main effect of generation time ( $T_G$ ),  $F(1, 88) = 1.64$ ,  $MSE = .09$ ,  $\eta^2 = .02$ , nor any two-way interactions with  $T_G$ , were observed [Age x  $T_G$ ,  $F(1, 88) < 1$ ,  $MSE = .09$ ,  $\eta^2 = .00$ ;  $T_G$  x Contingency,  $F(4, 352) = 2.15$ ,  $MSE = .09$ ,  $\eta^2 = .02$ ,  $p = .08$ ;  $T_G$  x  $T_M$ ,  $F(1, 88) < 1$ ,  $MSE = .09$ ,  $\eta^2 = .00$ ]. However, there was a three-way Age x  $T_G$  x Contingency interaction,

$F(4, 352) = 3.36, MSE = .09, \eta^2 = .04$ . The linear trend for this interaction was significant,  $F(1, 88) = 4.72, MSE = .21, \eta^2 = .05$ . To investigate this interaction further, tests of simple  $T_G \times$  Contingency interactions were conducted for each age group. A significant  $T_G \times$  Contingency interaction was found for young adults,  $F(4, 184) = 4.41, MSE = .09$ , but not for older adults,  $F(4, 184) < 1, MSE = .10$ . Subsequent tests of simple effects confirmed that young adults in the  $T_G$ -short condition had derived contingency judgments further from zero for the  $-.75$  contingency problem ( $M = -.59, SE = .08$ ) than those in the  $T_G$ -long condition ( $M = -.36, SE = .08$ ),  $F(1, 46) = 4.06, MSE = .16$ ; young adults in the  $T_G$ -short condition also had derived contingency judgments further from zero for the  $.75$  contingency problem ( $M = .65, SE = .08$ ) than those in the  $T_G$ -long condition ( $M = .38, SE = .08$ ),  $F(1, 46) = 5.94, MSE = .15$ . Furthermore, in the  $T_G$ -short condition young adults had significantly different derived contingency judgments than older adults,  $F(4, 184) = 5.35, MSE = .10$ , but in the  $T_G$ -long condition no age differences were found,  $F(4, 184) < 1$ . Tests of simple effects revealed that the differences were again in the  $\pm .75$  conditions [ $-.75, F(1, 46) = 5.46, MSE = .17$ ;  $-.375, F(1, 46) = 2.68, MSE = .05$ ;  $0, F(1, 46) < 1$ ;  $.375, F(1, 46) = 2.59, MSE = .07$ ;  $.75, F(1, 46) = 4.38, MSE = .21$ ].

No main effect of temporal contiguity ( $T_M$ ) was observed,  $F(1, 88) = 3.53, MSE = .09, \eta^2 = .04, p = .06$ , but a significant  $T_M \times$  Contingency interaction was found,  $F(4, 352) = 8.26, MSE = .09, \eta^2 = .09$ . The linear trend for this interaction was significant,  $F(1, 88) = 13.24, MSE = .21, \eta^2 = .13$ , showing that, as for direct contingency judgments, the contingency function slope was steeper for participants in the  $T_M$ -short condition than for those in the  $T_M$ -long condition. As for judgment error scores, but unlike direct

contingency judgments, the Age x  $T_M$  interaction was significant,  $F(1, 88) = 4.86$ ,  $MSE = .09$ ,  $\eta^2 = .05$ . Follow-up tests of simple effects revealed that young and older adults in the  $T_M$ -short condition gave different derived contingency judgments than those in the  $T_M$ -long condition [Young,  $F(4, 352) = 5.76$ ,  $MSE = .09$ ; Older,  $F(4, 352) = 2.97$ ,  $MSE = .09$ ]. However, follow-up analyses of simple effects showed no significant age differences for either the  $T_M$ -short condition,  $F(4, 352) = 2.72$ ,  $MSE = .09$ , or the  $T_M$ -long condition,  $F(4, 352) = 1.25$ ,  $MSE = .09$ . Unlike both direct judgments and judgment error, the Age x  $T_M$  x Contingency interaction was not significant,  $F(4, 352) < 1$ ,  $MSE = .09$ ,  $\eta^2 = .01$ .

The three-way Age x  $T_G$  x  $T_M$  interaction was not significant,  $F(1, 88) < 1$ ,  $MSE = .09$ ,  $\eta^2 = .01$ , but there was a three-way  $T_G$  x  $T_M$  x Contingency interaction,  $F(4, 352) = 2.46$ ,  $MSE = .09$ ,  $\eta^2 = .03$ . Follow-up tests of simple  $T_M$  x Contingency interactions for each level of  $T_G$  were conducted to further investigate this three-way interaction. A significant  $T_M$  x Contingency interaction was found for the  $T_G$ -short condition,  $F(4, 184) = 8.36$ ,  $MSE = .10$ , but not for the  $T_G$ -long condition  $F(4, 184) = 1.53$ ,  $MSE = .08$ . Subsequent tests of simple effects revealed that, for the  $T_G$ -short condition, there were differences between  $T_M$ -short and  $T_M$ -long for the  $-.75$ ,  $F(1, 46) = 7.96$ ,  $MSE = .16$ ,  $.375$ ,  $F(1, 46) = 8.41$ ,  $MSE = .07$ , and  $.75$ ,  $F(1, 46) = 7.83$ ,  $MSE = .20$ , contingencies [all other  $F$ 's  $< 1$ ]. Compared to participants in the  $T_M$ -short condition, participants in the  $T_M$ -long condition rated these contingencies closer to zero. The Age x  $T_G$  x  $T_M$  x Contingency interaction was not significant,  $F(4, 352) < 1$ ,  $MSE = .09$ ,  $\eta^2 = .00$ , indicating that this effect of  $T_G/T_M$  condition on contingency was not different for the two age groups.

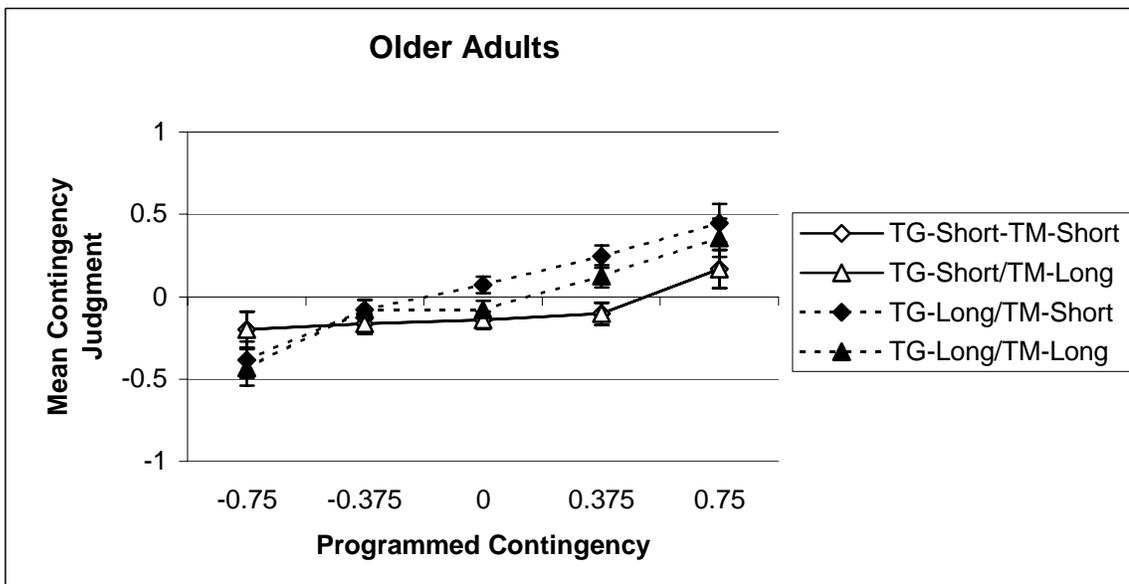
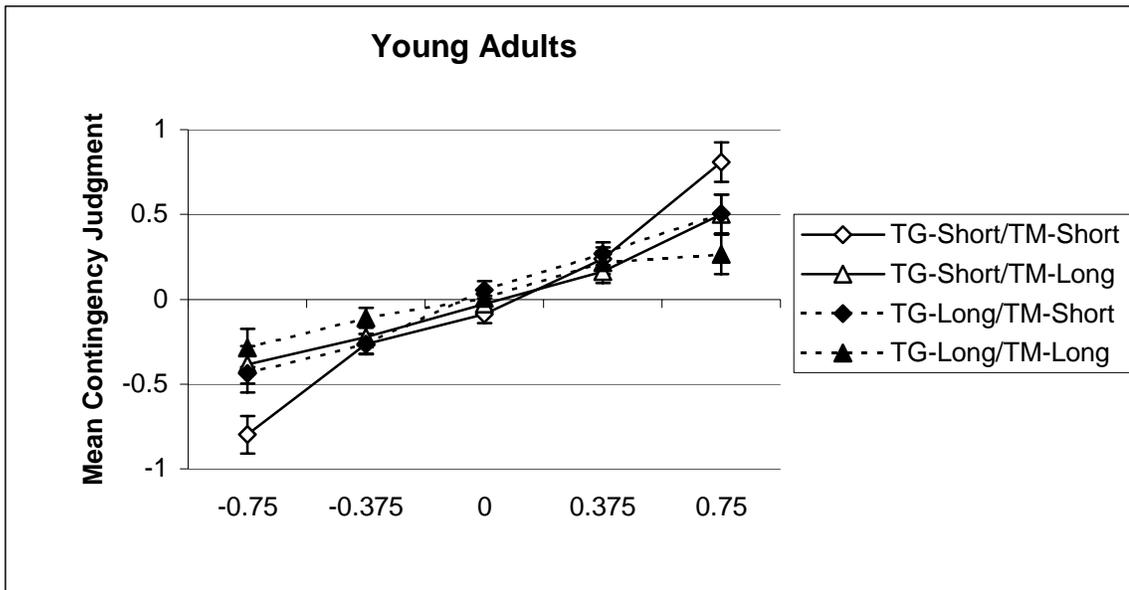


Figure 10. Young and older adults' mean derived contingency judgments by condition for each programmed R-O contingency.

### Density Bias

Previous research has found young adult participants' direct contingency judgments to be biased based on the overall probability of an outcome occurring, in that judgments of programmed non-contingencies are higher when the probability of an outcome given a response ( $P(O/R)$ ) is higher (e.g., Allan & Jenkins, 1980; Chatlosh et al., 1985; but see Wasserman et al., 1983). To address the question of whether there was a density bias in the present data, and to examine whether this effect varied for young and older adults and for the different timing manipulations, data for the three noncontingent problems ( $P(O/R) / P(O/\sim R) = .875/.875, .500/.500, .125/.125$ ) were submitted to a 2 (Age) x 2 ( $T_M$ ) x 2 ( $T_G$ ) x 3 (Outcome Density) ANOVA.

The results, presented in Table 2, showed that participants were indeed influenced by how often an outcome occurred. Even though the programmed contingency was the same for the three noncontingent problems, participants gave these problems significantly different contingency ratings,  $F(2, 176) = 37.59, MSE = .13, \eta^2 = .30$ . Contrast analyses showed that these contingency judgments followed a pattern like that of the overall outcome probability—the .875/.875 problem ( $M = .26, SE = .04$ ) was rated significantly higher than the .500/.500 problem ( $M = .05, SE = .03$ ),  $F(1, 88) = 21.19, MSE = .21, \eta^2 = .19$ , which was significantly higher than the .125/.125 problem ( $M = -.19, SE = .04$ ),  $F(1, 88) = 27.17, MSE = .21, \eta^2 = .24$ . Thus, for both young and older adults, the greater the probability of an outcome, the higher contingency was rated, even when there was actually no relation between the events at all. Interestingly, this effect of outcome density was qualified by an Age x  $T_G$  x Outcome Density interaction,  $F(2, 176) = 3.55, MSE = .13, \eta^2 = .04$ . To investigate this interaction further, analyses of  $T_G$  x Outcome Density

interaction effects were conducted for each age group. The interaction was not significant for young adults,  $F(2, 92) < 1$ , but was significant for older adults,  $F(2, 92) = 3.64$ ,  $MSE = .14$ . Subsequent tests of simple effects revealed that older adults in the  $T_G$ -long condition judged the .125/.125 non-contingent problem as more negative ( $M = -.24$ ,  $SE = .06$ ) than those in the  $T_G$ -short condition ( $M = .02$ ,  $SE = .06$ ),  $F(1, 46) = 8.59$ ,  $MSE = .09$ . Finally, there was a main effect of temporal contiguity ( $T_M$ ),  $F(1, 88) = 3.97$ ,  $MSE = .03$ ,  $\eta^2 = .04$ , showing that participants in the  $T_M$ -short condition rated the zero contingencies higher ( $M = .08$ ,  $SE = .03$ ) than those in the  $T_M$ -long condition ( $M = .00$ ,  $SE = .03$ ). This finding is consistent with the previously discussed effects of  $T_M$  condition.

Table 2

*Density Bias for Young and Older Adults*

	$T_G$ -short		$T_G$ -long	
	$T_M$ -short	$T_M$ -long	$T_M$ -short	$T_M$ -long
Young				
.875/.875	.25 (.12)	.20 (.12)	.37 (.11)	.00 (.11)
.500/.500	-.05 (.06)	-.03 (.06)	.04 (.09)	.04 (.09)
.125/.125	-.44 (.09)	-.241 (.09)	-.20 (.12)	-.235 (.12)
Older				
.875/.875	.31 (.12)	.18 (.12)	.40 (.11)	.40 (.11)
.500/.500	.18 (.12)	-.01 (.06)	.12 (.09)	.08 (.09)
.125/.125	.04 (.12)	-.01 (.09)	-.12 (.12)	-.35 (.12)

## Chapter Five

### Discussion

The goal of this study was to examine the differential effects of task timing manipulations on young and older adults' contingency learning ability. This study used a response-outcome (R-O) contingency learning task in which participants were instructed to judge the extent to which a simple action caused an outcome occurrence. In particular, this study examined what happens to young and older adults' contingency judgments with more or less stringent timing manipulations of the contingent events. Specifically, the time interval during which participants could generate a causal response ( $T_G$ ) was either short or long. And the time between the causal event and the outcome, during which the causal event must be held in memory ( $T_M$ ), was short or long. These timing manipulations were constructed to test the theory that the speed with which one can process information will affect associative learning (Salthouse, 1996; Wagner, 1981) and therefore contingency learning (Shanks, 1987). It was expected, because of slower processing speed associated with cognitive aging, that older adults would show less accurate contingency judgments than young adults, particularly in the less optimal task timing conditions.

#### Direct Contingency Judgments

The results corroborate previous findings that adult humans are able to accurately judge the relationships between contingent response-outcome events (e.g., Allen & Jenkins, 1980; Chatlosh et al., 1985; Wasserman et al., 1983; Wasserman et al., 1993). Like these previous studies, direct judgments of contingency closely paralleled the

programmed contingencies set up by the experimenter—positive contingencies were given higher judgments, and negative contingencies were given lower judgments. Furthermore, this important learning ability was shown to be affected by aging, also in keeping with previous research (e.g., Chasseigne et al., 1997; Mutter & Pliske, 1996; Mutter & Williams, 2004; Parr & Mercier, 1998). In particular, and as in previous studies, the difference between young and older adults' contingency judgments occurred primarily for the negative contingency relationships in which the causal response prevented the outcome occurrence. Even though older adults were able to judge positive contingencies relatively accurately, much like young adults, some deficit associated with aging was unique to the learning of negatively contingent events.

Although not precisely in the hypothesized direction, task timing conditions did affect young and older adults' contingency judgments differently in this study. First, young and older adults' overall direct contingency judgments were differentially impacted by combining response generation time and R-O interval manipulations. In the current study, contingencies were symmetrical around zero; thus, overall judgment scores that are closer to zero indicate more accurate contingency estimation. Young adults' overall estimates were unaffected by the combination of these conditions, whereas older adults showed a positive bias in their contingency judgments. This positive bias was particularly evident for older adults when given a long versus a short generation time in conjunction with a long R-O interval.

Despite this evidence for age differences in the different response generation and R-O timing conditions, generation time ( $T_G$ ) generally did not have a strong effect on young and older adults' contingency learning. Varying the time interval during which

participants could generate a response was intended to test the effects of the limited time mechanism of processing speed (e.g., Salthouse, 1996) on the contingency learning ability of older adults. In particular, it was hypothesized that providing a short time to generate a response would limit processing of the causal event for older participants with slower processing speed, thereby impeding contingency learning. No differences were found for young or older adults based on this timing manipulation alone, and the only difference observed for older adults was in the long versus short generation time condition in conjunction with a long memory time. Thus, the data suggest that the limited time mechanism of processing speed may not have a significant impact on the contingency learning ability of older adults.

However, before discarding this mechanism of Salthouse's (1996) theory, it seems prudent to examine the task used to test this theory. A potential limitation in this study's ability to test the limited time mechanism may have been the R-O paradigm used. In order to examine causal contingencies, in which one estimated the extent to which his or her behavior affected an outcome event, a motor response had to be made. In order to do so, it was necessary to allow enough time for both young and older adults to generate a response. However, allowing a full 750 msec for a response in a condition supposed to stress sensory processing ability might still not have sufficiently impeded stimulus processing. After all, the causal stimulus had certainly been processed enough for a motor response to be generated. Thus, the limited time mechanism may not have been fully tested in this study. In order to further investigate the possibility that limiting the time to process the first event impedes its association with a contingent event, future research might use a cue-outcome (C-O) contingency paradigm requiring passive observation of

events without a required response. In this way, stimuli could be presented even more quickly and slower processors' sensory representations would be more likely to be differentially fragile.

The  $T_M$  manipulation used in this study demonstrated that contingency judgments were affected by increasing the amount of time between the response and outcome events. As predicted, this memory time manipulation affected the direct contingency judgments and judgment error of both young and older adults. The finding that reduced temporal contiguity of contingent events affects young adults' contingency learning corroborates previous research (e.g., Shanks, Pearson, & Dickinson, 1989; but see also Chatlosh, et al., 1985), in that young adults tended to underestimate contingent relationships given a longer R-O interval. However, in contrast to predictions, the effect of age was not due to an improvement in older adults' contingency judgments given the more optimal short R-O interval but rather to the decrease in young adults' contingency judgment accuracy given the less optimal long R-O interval. Interestingly, these findings parallel the free operant task findings of Mutter and Williams (2004), for which the age differences found in short versus long R-O interval conditions were due not to the hypothesized improvement in older adults' judgments given a short R-O interval but rather to the decline in young adults' judgments given a long R-O interval. In fact, in both that study and the current research, young adults' performance in the long R-O condition was much like that of older adults.

The finding that young adults given a short R-O interval gave more accurate contingency judgments than those given a long R-O interval also suggests that temporal contiguity is important to contingency learning. This explanation lends support for the

simultaneity mechanism of processing speed tested in the current study, in that the short R-O interval promoted overlapping memory activations for the causal and outcome events, whereas the long R-O interval lessened the overlap of memory activations.

Also interesting, however, is the finding that young adults given a long R-O interval gave similar judgments to older adults in both R-O interval conditions. Comparing judgment patterns of the two age groups in the short R-O interval conditions may aid understanding as to what cognitive changes associated with aging might be related to less accurate contingency judgment ability. It is possible that the lessened overlap of events in young adults' working memory given a long R-O interval is effectively similar to the overlap of events in older adults' working memory even given a short R-O interval. In other words, the simultaneity mechanism of processing speed may affect older adults to the extent that even more temporally contiguous events are less able to be simultaneously activated in working memory, and thus are less able to be associated into an accurate contingency judgment (e.g., Salthouse, 1996; Wagner, 1981). In this sense, this study found support for a link between processing speed and contingency learning. This fundamental deficit in associative learning with aging is corroborated with research such as that of Mitchell and colleagues (2000), who have shown an age-related deficit in the ability to accurately associate the individual features of an event. Thus, older adults may be less able to perceptually bind the component features of a contingent relationship. That and the current research align with the idea that there is a deficit in older adults' ability to judge contingency that cannot be eased by improving the external timing of events.

### Derived Contingency Judgments

This study also confirmed that derived judgments of contingency based on conditional probability judgments (i.e., the probability of an outcome when a response is given and the probability of the outcome when a response is not made) are sensitive to contingency. Participants gave conditional probability judgments that differed as a function of programmed R-O contingency.

Derived contingency judgments showed effects of response generation time that differed somewhat from those seen for direct contingency judgments. For derived contingency judgments, young adults given a short generation time gave more accurate estimates for the strong  $\pm .75$  contingencies than young adults given a long generation time and older adults in either generation time condition. Older adults given either a short or long generation time showed no difference in their derived contingency judgments. This outcome did not support the expectation that young adults would show no difference in judgments based on generation time, but rather that older adults' judgments would be less accurate given a short than a long time to generate a response. Instead, the observed age differences resulted from an improvement in young adults' judgments in what was hypothesized to be the less optimal timing situation, rather than to a deficit in older adults' judgments given the same timing situation. However, because a similar outcome was not found for direct contingency judgments or for judgment error, perhaps the generation time effect for young adults is unique to their judgments of  $P(O/R)$  and  $P(O/\sim R)$  when the programmed difference between these conditional probabilities is greatest. It is possible that a short generation time for young adults, who have a faster processing speed, allowed even better overlap of memory activation for the response and

outcome events, particularly for a problem situation requiring less memory demand like conditional probability estimation (as opposed to direct estimation of contingency). In such a case, the short generation time, hypothesized to be the least optimal condition, may have actually been the most optimal, and older adults simply did not show improvement in judgments regardless of condition.

In addition, participants given a short generation time in conjunction with a short R-O interval had more accurate derived contingency judgments for the strong  $\pm .75$  contingencies than those given a short generation time with a long R-O interval. No differences were found for those given a long generation time or for age group. Again, perhaps a shorter time to generate a response was actually more beneficial to the perception of strong contingency relationships than hypothesized, because it actually facilitated the learning of the association between the response or context with the ensuing outcome.

#### Direct versus Derived Contingency Judgments

Of greater interest is the difference in the effect of generation time in conjunction with temporal contiguity found between direct and derived contingency judgments. This is primarily because age differences associated with both timing conditions were found only for direct contingency judgments; thus, this finding indicates that the effects of task timing condition on contingency judgments corresponding to aging are more pronounced when direct judgments of contingency are required. Previous research has suggested that conditional probability judgments may be simpler to make than contingency judgments, particularly if subjective estimate of these probability estimates are somehow used to calculate contingency (see Wasserman et al., 1993). Moreover, it is possible that the

cognitive mechanisms required for simple associative learning between a target event in addition to the context and the outcome, as well as learning the association between the context alone and the outcome (e.g., Rescorla & Wagner, 1972), are less affected by slower processing speed in older adults than using these sources of information to make a direct estimate of the relationship between contingent events (e.g., Shanks, 1987).

### Conclusion

Overall, these findings again demonstrate that contingency learning ability is affected by cognitive aging. Furthermore, by investigating how the ability to judge contingency is affected by different task timing conditions, the current study provides new information about what factors are important to learning causal relationships. Of greatest interest was the finding that older adults did not give improved contingency judgments even in theoretically optimal task timing conditions. Furthermore, while young adults' judgments looked much like those of older adults' in the theoretically less optimal timing conditions, their judgments improved in the more optimal conditions. The results of the current study lend support for a processing speed theory of contingency learning, although future research is needed to fully investigate this explanation. Older adults' reduced ability to judge contingent relationships in the environment may be due to a fundamental deficit in the ability to associate or bind the events simultaneously in working memory.

## References

- Allan, L. G. (1993). Human contingency judgments: Rule based or associative? *Psychological Bulletin, 114*(3), 435-448.
- Allan, L. G., & Jenkins, H. M. (1980). The judgment of contingency and the nature of the response. *Canadian Journal of Psychology, 34*, 1-11.
- Alloy, L. B. & Tabachnik, N. (1984). Assessment of covariation by humans animals: The joint influence of prior expectations and current situational information. *Psychological Review, 91*(1), 112-149.
- Birren, J. E. (1974). Translations in gerontology: From lab to life: Psychophysiology and speed of response. *American Psychologist, 29*, 808-815.
- Bors, D. A., & Forrin, B. (1995). Age, speed of information processing, recall, and fluid intelligence. *Intelligence, 20*, 229-248.
- Bryan, J., & Luszcz, M. A. (1996). Speed of information processing as a mediator between age and free recall performance. *Psychology and Aging, 11*, 3-9.
- Canestrari, R. E., Jr. (1963). Paced and self-paced learning in young and elderly adults. *Journal of Gerontology, 18*, 165-168.
- Chasseigne, G., Mullet, E., Stewart, T. R., (1997). Aging and multiple cue probability learning. *Acta Psychologica, 97*, 235-252.
- Chatlosh, D. L., Neunaber, D. J., Wasserman, E. A. (1985). Response-outcome contingency: Behavioral and judgmental effects of appetitive aversive outcomes and college students. *Learning and Motivation, 16*, 1-34.
- Crocker, J. (1981) Judgment of covariation by social perceivers. *Psychological Bulletin, 90*(2), 272-292.

- Cunningham, W. (1989). Intellectual abilities, speed of response, and aging. In V. L. Bengtson & K. W. Schaie (Eds.), *The course of later life: Research and reflections*. New York: Springer.
- Dickinson, A. & Shanks, D. (1985). Animal conditioning and human causality judgment. In L. G. Nilsson, & T. Archer (Eds.), *Perspectives on Learning and Memory* (pp. 167-191). Hillsdale, NJ: Erlbaum.
- Domjan, M. (2003). *The principles of learning and behavior (Fifth Edition)*. Belmont, CA: Wadsworth/Thompson Learning.
- Dunlosky, J. & Connor, L. T. (1997). Age differences in the allocation of study time account for age differences in memory performance. *Memory and Cognition*, 25, 691-700.
- Finkbiner, R. G. & Woodruff-Pak, D. S. (1991). Classical eyeblink conditioning in adulthood: Effects of age and interstimulus interval on acquisition in the trace paradigm. *Psychology and Aging*, 6(1), 109-117.
- Fisk, J. E., & Warr, P. (1996). Age-related impairment in associative learning: The role of anxiety, arousal, and learning self-efficacy. *Journal of Personality and Individual Differences*, 21(5), 675-686.
- Frensch, P. & Miner, C. (1994). Effects of presentation rate and individual differences in short-term memory capacity on an indirect measure of serial learning. *Memory & Cognition*, 22(1), 95-110.
- Hammond, L. J. (1980). The effect of contingency upon the appetitive conditioning of free-operant behavior. *Journal of the Experimental Analysis of Behavior*, 34, 297-304.

- Hertzog, C. (1989). Influences of cognitive slowing on age differences in intelligence. *Developmental Psychology, 25*, 636-651.
- Hertzog, C., Kidder, D. P. Powell-Moman, A., & Dunlosky, J. (2002). Aging and monitoring associative learning: Is monitoring accuracy spared or impaired? *Psychology and Aging, 17*(2), 209-225.
- Jenkins, H. M. & Ward, W. C. (1965). Judgment of contingency between responses and outcomes. *Psychological Monographs: General and Applied, 79*(1), 1-17.
- Kail, R., & Salthouse, T. A. (1994). Processing speed as a mental capacity. *Acta Psychologica, 86*, 199-225.
- Kausler, D. H. (1994). *Learning and memory in normal aging*. San Diego, CA: Academic Press.
- Kyllonen, P. C., Tirre, W. C. & Christal, R. E. (1991). Knowledge and processing speed as determinants of associative learning. *Journal of Experimental Psychology: General, 120*(1), 57-79.
- Levine, B., Stuss, D. T., & Milberg, W. P. (1997). Effects of aging on conditional associative learning: Process analyses and comparison with focal frontal lesions. *Neuropsychology, 11*, 367-381.
- Lindenberger, U., Mayr, U., & Kliegl, R. (1993). Speed and intelligence in old age. *Psychology and Aging, 8*, 207-220.
- Mercier, P., & Parr, W. (1996). Intertrial interval, stimulus duration, and number of trials in contingency judgments. *British Journal of Psychology, 87*, 549-566.
- Miller, R. R., Barnet, R. C., & Grahame, N. J. (1995). Assessment of the Rescorla-Wagner model. *Psychological Review, 117*(3), 363-386.
- Mitchell, K. J., Johnson, M. K., Raye, C. L., Mather, M., & D'Esposito, M. (2000).

- Aging and reflective processes of working memory: Binding and test load deficits. *Psychology and Aging*, 15(3), 527-541.
- Monge, R. H. & Hultsch, D. F. (1971). Paired-associate learning as a function of adult age and the length of the anticipation and inspection intervals. *Journal of Gerontology*, 26(2), 157-162.
- Mutter, S. A. & Pliske, R. M. (1996). Judging event covariation: Effects of age and memory demand. *Journal of Gerontology: Psychological Sciences*, 51B(2), P70-P80.
- Mutter, S. A. & Williams, T. (2004). Aging and the detection of contingency in causal learning. *Psychology and Aging*, 19, 13-26.
- Myerson, J., Hale, S., Poon, L., Wagstaff, D., & Smith, G. (1990). The information-loss model: A mathematical theory of age-related cognitive slowing. *Psychological Review*, 97, 475-487.
- Parr, W. V. & Mercier, P. (1998). Adult age differences in on-line contingency judgments. *Canadian Journal of Experimental Psychology*, 52(3), 147-158.
- Rabinowitz, J. C. (1989). Age deficits in recall under optimal study conditions. *Psychology and Aging*, 4(3), 378-380.
- Rescorla, R. A. (1985). Associationism in animal learning. In Nilsson, L. & Archer, T. (Eds.). *Perspectives on learning and memory*. Hillsdale, NJ: Erlbaum.
- Rescorla, R. A. & Wagner, A. R. (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning II: Current research and theory* (pp. 64-99). New York: Appleton-Century-Crofts.

- Salthouse, T. A. (1991). *Theoretical perspectives on cognitive aging*. Hillsdale, NJ: Erlbaum.
- Salthouse, T. A. (1993). Speed mediation of adult age differences in cognition. *Developmental Psychology, 29*, 722-738.
- Salthouse, T. A. (1994a). The nature of the influence of speed on adult age differences in cognition. *Developmental Psychology, 30*(2), 240-259.
- Salthouse, T. A. (1994b). Aging associations: Influence of speed on adult age differences in associative learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 1486-1503.
- Salthouse, T. A. (1996). The processing speed theory of adult age differences in cognition. *Psychological Review, 103*(3), 403-428.
- Salthouse, T. A. & Babcock, R. L. (1991). Decomposing adults age differences in working memory. *Developmental Psychology, 27*(5), 763-776.
- Schaie, K. W. (1990). Correction to Schaie (1989). *Psychology and Aging, 5*, 171.
- Shanks, D. R. (1987). Acquisition functions in contingency judgment. *Learning and Motivation, 18*, 147-166.
- Shanks, D. R. & Dickinson, A. (1991). Instrumental judgment and performance under variations in action-outcome contingency and contiguity. *Memory & Cognition, 19*(4), 353-360.
- Shanks, D. R., Pearson, S. M., Dickinson, A. (1989). Temporal contiguity and the judgement of causality by human subjects. *The Quarterly Journal of Experimental Psychology, 41B*(2), 139-159.
- Sloman, S. A. (1996). The empirical case for two systems of reasoning. *Psychological*

*Bulletin*, 119(1), 3-22.

Speiler, D. H. & Balota, D. A. (1996). Characteristics of associative learning in younger and older adults: Evidence from an episodic priming paradigm.

*Psychology and Aging*, 11(4), 607-620.

Wagner, A. R. (1981). SOP: A model of automatic memory processing in animal

behavior. In N.E. Spear and R. Miller (Eds.) *Information processing in animals:*

*Memory mechanisms*, (pp. 5-47). Hillsdale, NJ: Erlbaum.

Wasserman, E. A., Chatlosh, D. L., Neunaber, D. J. (1983). Perception of causal relations

in humans: Factors affecting judgments of response-outcome contingencies under

free-operant procedures. *Learning and Motivation*, 14, 406-432.

Wasserman, E. A., Elek, S. M., Chatlosh, D. L., & Baker, A. G. (1993). Rating causal

relations: Role of probability in judgments of response-outcome contingency.

*Journal of Experimental Psychology: Learning, Memory and Cognition*, 19, 174-188.

Woodruff-Pak, D. S. & Thompson, R. F. (1988). Classical conditioning of the eyeblink

response in the delay paradigm in adults aged 18-83 years. *Psychology and Aging*,

3(3), 219-229.

Woodruff-Pak, D. S. & Jaeger, M. E. (1998). Predictors of eyeblink classical

conditioning over the adult age span. *Psychology and Aging*, 13(2), 193-205.

Appendix A

Derived Contingencies

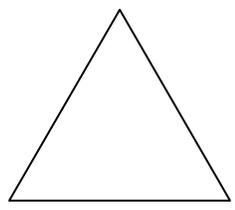
		<i>P(O/R)</i>		
		<i>.875</i>	<i>.500</i>	<i>.125</i>
<i>P(O/~R)</i>	<i>.875</i>	0	-.375	-.750
	<i>.500</i>	.375	0	-.375
	<i>.125</i>	.750	.375	0

Experiment Instructions

(Adapted from Mutter & Williams, 2004)

Please read the following instructions very carefully. Take as much time as you like and ask as many questions as you like.

Your task in this experiment is to judge the extent to which you can cause something to happen on the computer screen. On each trial you will see a triangle above a series of boxes that looks like this:



Your task is to find out whether pressing the SPACEBAR has any effect on whether or not the triangle flashes. Now press the SPACEBAR and see what happens [the triangle flashed when the SPACEBAR was pressed]. The triangle flashes.

Sometimes the triangle will flash of its own accord, like this: [the triangle automatically flashed three times].

During each trial, you must decide whether to press or not press the SPACEBAR. Now look at the boxes on the bottom of the screen. These boxes provide information about the amount of time you have in a trial to make your decision about whether to press or not press the SPACEBAR. At the beginning of each trial the boxes will appear filled and will count down one by one to indicate the amount of time remaining for your decision. If you decide to press the SPACEBAR, you must press it within this time period. If you decide not to press the spacebar, you simply do nothing during this time period. Now press the RIGHT ARROW key to see what the boxes will do [The boxes all turned black and emptied back to white, one by one, from right to left. The short generation time condition had five boxes on the bottom of the screen; the long generation time had 15 smaller boxes on the bottom of the screen. In both conditions, a box emptied every 150 ms.].

In order to make accurate estimates, it is to your advantage to press the SPACEBAR some of the time and not press it some of the time. In addition, because your task is to find out whether pressing the SPACEBAR has any affect on the triangle, please **DO NOT HOLD DOWN THE SPACEBAR** at any time during the experiment.

You will be given a practice problem then nine different problems. The relationship between pressing the SPACEBAR and whether or not the triangle flashes

will not change within each problem, but may well vary from one problem to the next.

Therefore, it is very important that you not let your judgment on any given problem affect your judgment on any of the other problems. In other words, treat each problem as if it is a new problem.

After each of the problems is completed, you will be asked to evaluate the relationship between pressing the SPACEBAR and the illumination of the triangle, based on your experience over the course of the entire problem. You will make your judgment using a scale from  $-100$  and  $+100$ .  $+100$  indicates that pressing the SPACEBAR always causes the triangle to flash,  $-100$  indicates that pressing the SPACEBAR always prevents the triangle from flashing, and  $0$  indicates that pressing the SPACEBAR has no effect on whether or not the triangle flashes.

You will then be asked to suppose you see a new screen with the triangle outline, and you PRESS THE SPACEBAR. You will be asked to estimate the probability that the triangle would flash, based on your experiences during the problem you just finished. You will type in a number to indicate your estimate of this probability, based on the scale shown below. Note that the scale ranges from  $0\%$  to  $100\%$ . The value  $0\%$  means the triangle definitely would not flash when you press the SPACEBAR. The value  $50\%$  means the triangle is as likely to flash as to not flash ( $50/50$  chance). And the value  $100\%$  means the triangle definitely would flash when you press the SPACEBAR.

You will then be asked to imagine you see a new screen with the triangle outline, and you DO NOT PRESS THE SPACEBAR. You will be asked to estimate the probability that the triangle would flash, based on your experiences during the problem you just finished. You will type in a number to indicate your estimate of this probability,

based on the scale shown below. Note that the scale ranges from 0% to 100%. The value 0% means the triangle definitely would not flash when you press the SPACEBAR. The value 50% means the triangle is as likely to flash as to not flash (50/50 chance). And the value 100% means the triangle definitely would flash when you press the SPACEBAR..

You will be able to take as much time as you need when making your judgments. Because judgment accuracy is VERY important, you will earn \$0.25 for each accurate estimate you make (for a total of \$2.25 EXTRA earnings possible).

Do you have any questions before you start the practice problem?

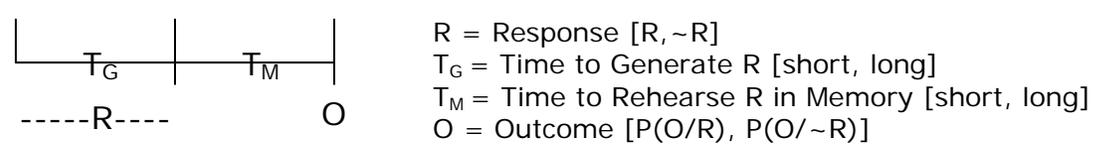
Please press the RETURN key when you are ready to begin the practice problem.

[The remaining instructions appeared after the practice problem was completed].

Now you will begin the first problem. Feel free to take a short break in between problems. Because it is very important you understand what you are supposed to do, please ask the experimenter if you have any questions. If you do not have any questions, press the RETURN key to begin.

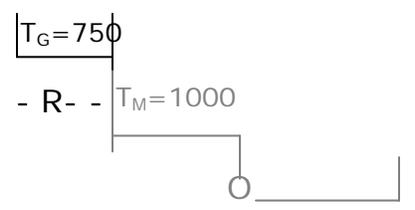
Appendix B

Experiment Manipulations (all times are in milliseconds)

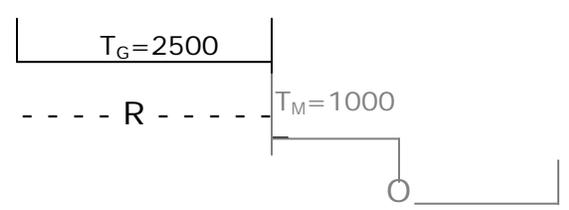


1. Testing the Limited Time Mechanism: Short vs. Long Generation Time ( $T_G$ )

a. Short Generation Time ( $T_{G-Short} T_{M-Short}$ )

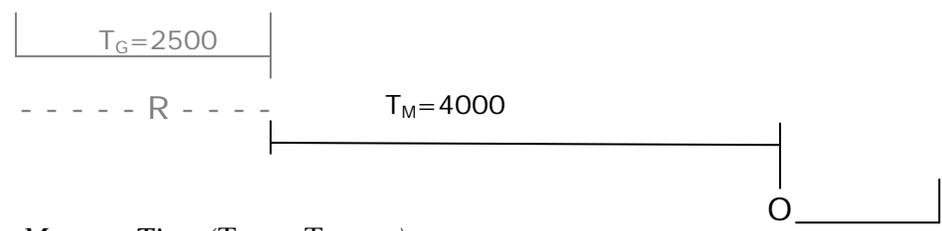


b. Long Generation Time ( $T_{G-Long} T_{M-Short}$ )



2. Testing the Simultaneity Mechanism: Long vs. Short Time in Memory ( $T_M$ )

c. Long Memory Time ( $T_{G-Long} T_{M-Long}$ )



d. Short Memory Time ( $T_{G-Long} T_{M-Short}$ )

