Adult Age Differences in Learning on a Sequentially Cued Prediction Task

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OBJECTIVES. Much of adaptive behavior relies on the ability to learn and generate predictions about relationships in the environment. Research on aging suggests both that there is an age deficit in the ability to learn sequential relationships and that this deficit in learning could underlie age differences reported in many decision-making tasks. This article introduces the Triplets Prediction Task (TPT) to investigate the learning of sequential relationships that underlies adaptive behavior.

METHOD. In the TPT, participants see 2 successive visual cues and then predict which target will follow. Unknown to participants, there is a predictive relationship between the first cue and the target such that each of 4 cues predicts 1 of 4 targets 85% of the time.

RESULTS. Although both age groups demonstrated learning on this task, an age deficit in learning appeared early and performance differences persisted throughout training. There was also evidence of age differences in the learning systems engaged during the task.

DISCUSSION. These results are consistent with previous studies of learning and prediction, and they support the growing literature showing adult age differences in decision making from experience.

KEY WORDS: Aging—Decision making—Learning—Prediction.

MANY everyday tasks, ranging from language comprehension and motor skill learning to categorization and decision making, involve exploiting knowledge about sequential relationships in the environment. This allows us to use temporal context to predict and respond appropriately to future events. Most studies of sequence learning have used the serial reaction time task (SRTT) and its variants (J. H. Howard & Howard, 1997; Nissen & Bullemer, 1987). In the SRTT, people respond to each of a series of events by pressing a corresponding button. Unbeknownst to them, predictive relationships are introduced and learning is demonstrated through faster reaction times (RTs) to predictable than to unpredictable events. Although faster responding on these tasks provides information about what the learner anticipates implicitly, in many real-world tasks, people must make explicit predictions on the basis of prior events. For example, decisions such as the mundane acquisition of breakfast cereal to more significant choices about financial investments are typically based on prior experience. Yet, relatively few studies have investigated how people learn to make decisions on the basis of prior experience.

The present study uses a prediction task to investigate how young and older adults learn to predict “target” events from the sequential context provided by previous “cue” events. Recent studies have demonstrated that although both young and older adults can learn probabilistic predictive relationships in their environments, learning is often impaired in older adults. For example, increasing task complexity by inserting random events between cue and target events (J. H. Howard & Howard, 1997; J. H. Howard, Howard, Dennis, & Kelly, 2008; Janacsek, Fiser, & Nemeth, 2012; Simon, Vaidya, Howard, & Howard, 2012) or making participants explicit about the predictive relationship exists (D. V. Howard & Howard, 2001; Lukacs & Kemeny, 2012) impaired performance in older adults relative to young adults. As discussed by Rieckmann and Bäckman (2009), it seems that although older adults were able to learn probabilistic relationships, increasing complexity and/or awareness either interfered with their ability to learn or to use what they had learned.

This potential impairment in learning sequential relationships has serious implications for decision making in older adults. As the world population ages, increasing numbers of older adults are being asked to take more personal responsibility for decisions where they have limited knowledge or experience, including finance and health care, raising critical questions for policymakers and caregivers, as well as for older adults themselves.

A recent meta-analysis of 29 studies of risky decision making and aging reported that older adults show impairment only on decision-making tasks that require learning (Mata, Josef, Samanez-Larkin, & Hertwig, 2011).
For example, when both young and older adults performed two decision-making tasks, one which required learning and one which did not, age-related differences emerged only on the former (Zamarian, Sinz, Bonatti, Gamboz, & Delazer, 2008). Thus, there is strong support for the idea that age deficits in learning underlie many of the age differences seen in decision making.

**Triplets Prediction Task**

In this study, we seek to characterize the associative learning (AL) of sequential regularities that underlies decision making in unfamiliar domains. To accomplish this, we introduce the Triplets Prediction Task (TPT), a variant of the Triplets Learning Task (J. H. Howard et al., 2008), to investigate the learning underlying decision making in young and older adults. On each trial of the TPT, participants observe two cue events and then predict which of four possible target events will occur. An event occurs when one of four circles fills in, and we introduce statistical dependencies such that the target is *more* or *less* predictable from the cues. However, unlike the Triplets Learning Task in which participants simply respond to the target, in the TPT, participants predict which target will occur on each trial.

The TPT has some similarities with the Weather Prediction Task (Gluck, Shohamy, & Myers, 2002) in that people are asked to use cues to repeatedly make predictions, and learning of the cue–outcome associations occurs incrementally over time in response to feedback. However, unlike Weather Prediction Task, cues in the TPT are presented sequentially instead of simultaneously and participants choose between four rather than two potential outcomes on each trial.

Recent dual-system theories of AL suggest that learning in the TPT is likely based on two systems, a *fast* system characterized by acquisition of flexible associations mediated by the medial temporal lobes and a *slow* system characterized by acquisition of rigid associations mediated by the striatum (Henke, 2010; Maddox & Ashby, 2004). In previous work, these have been referred to as the explicit and implicit systems, respectively (Squire & Zola, 1996), with only the former thought to rely on working memory and the latter (processes such as significance detection) to underlie multiple trial learning. In line with Henke’s (2010) theory, recent work has suggested that both of these systems may be engaged during sequence learning (Schendan, Searl, Melrose, & Stern, 2003) and prediction learning tasks (Poldrack et al., 2001) and that these learning systems may be engaged differently by young and older adults (Dennis & Cabeza, 2011; Rieckmann, Fischer, & Bäckman, 2010; Simon et al., 2012). Given the similarities between the TPT and these other paradigms, we expect that both learning systems will be engaged during the TPT and that their relative contributions will vary with adult age.

The present study has two aims. First, using the TPT, we examine whether young and older adults can learn the probabilistic relationships between cues and targets. Second, we use measures of recall, recognition, and other neurocognitive functions to characterize the learning systems engaged by this task and how these differ in young and older adults.

**Method**

**Participants**

Sixteen young and 16 older volunteers participated (Table 1). The young volunteers were recruited from introductory psychology classes at The Catholic University of America and received course credit for their participation. The older volunteers were community-dwelling adults who responded to advertisements placed in regional newspapers; they received gift certificates for their participation. None of the participants had been in a similar study. The data for two young adults and two older participants who performed at chance (accuracy = 0.25), or were more than 3 SDs from the group mean, were excluded from all analyses.

The age groups were well matched in gender, self-rated health, and forward digit span. The older adults performed better on backward digit span and vocabulary, whereas young adults performed better on digit coding. Age differences on digit coding, a measure of processing speed, and vocabulary, a proxy for crystallized intelligence, are typical. The superior performance of older adults on backward digit span, a measure of working memory, although not typical, further suggests this sample includes high-functioning older adults.

**Design**

A $2 \times 2 \times 6$ (Age × Probability × Session) mixed factorial design was used, with age (older vs young) as a between-subjects factor and target probability (high vs low) and session (1–6) as within-subjects factors.

**Task**

On each trial, the two cues appeared for 250 ms each, separated by a 100 ms interstimulus interval and followed

**Table 1. Mean Values (With Standard Deviation in Parentheses) of Participant Characteristics**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Young adults</th>
<th>Older adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>10 females, 4 males</td>
<td>10 females, 4 males</td>
</tr>
<tr>
<td>Age (in years)</td>
<td>19.46 (1.82)</td>
<td>67.93 (6.06)**</td>
</tr>
<tr>
<td>Self-rated health*</td>
<td>4.57 (0.65)</td>
<td>4.29 (0.91)</td>
</tr>
<tr>
<td>WMS-III Digit Span Forward</td>
<td>10.71 (1.73)</td>
<td>11.00 (2.18)</td>
</tr>
<tr>
<td>WMS-III Digit Span Backwards</td>
<td>6.50 (1.61)</td>
<td>8.07 (1.73)*</td>
</tr>
<tr>
<td>WAIS Digit Coding</td>
<td>90.57 (10.80)</td>
<td>66.29 (14.60)**</td>
</tr>
<tr>
<td>NAART35 Vocabulary*</td>
<td>15.30 (8.09)</td>
<td>9.14 (5.56)*</td>
</tr>
<tr>
<td>N</td>
<td>14</td>
<td>14</td>
</tr>
</tbody>
</table>


*1 = poor, 5 = excellent.
*NAART Vocabulary is scored such that higher scores are related to poorer performance. For all other neuropsychological tests, higher scores indicate better performance.

*p < .05. **p < .001.
by a row of open circles (Figure 1). Participants predicted the spatial location of the target by button press after which the correct location of the target was displayed with the word “correct” in green or “incorrect” in red above the circles. Feedback remained on the screen for 2,000 ms. If participants failed to make a prediction within 5,000 ms, they received the “incorrect” feedback and the trial was aborted.

Unbeknownst to participants, there was a probabilistic predictive relationship between the locations of the first cue and the target; the location of the second cue was random. Thus, following J. H. Howard and colleagues (2008), these three-event sequences, or triplets, created a second-order task structure. Trials where the first cue and the target occurred in the same location were never presented because they are associated with strong preexisting response tendencies (D. V. Howard et al., 2004; Soetens, Melis, & Notebaert, 2004). In other words, 4 cue–target relationships were excluded, leaving 12 cue–target relationships for this task. For each participant, four cue–target relationships were high probability (the first cue predicted the target with .85 probability) and eight were low probability (.075 probability). For example, if the cue in location 1 predicted a target in location 3 with probability .85 (1×3, where x represents any location), then a target in location 2 (1×2) and a target in location 4 (1×4) would each occur with .075 probability, and location 1 never occurred. A postexperimental manipulation check verified that the presented probabilities were not significantly different from those programed, with high-probability relationships occurring on 84.6% of trials and low-probability relationships on 15.4% of trials overall.

**Procedures**

The Catholic University of America Institutional Review Board approved experimental procedures and participants gave informed consent. People were told they would see a series of circles and to guess where the third circle would appear on each trial. They were informed that one of the circles would be “correct” and that the other circles would be “incorrect,” that initially they would not know which circle was correct, but that they should try to remember which circle was correct so they could choose it the next time they saw that sequence, and that “some sequences are correct in some situations and incorrect in others.”

Participants completed six sessions of four, 70-trial blocks, for a total of 1,680 trials. They completed three on the first day and the remaining sessions on a second day, with an average of 3 days between visits. Participants were given a break between sessions and they were encouraged to take a short break between blocks. Neuropsychological tests, all of which are reported in Table 1, were administered between sessions of the TPT. Total testing time was approximately 2 hr per day.

At the end of the second day, explicit knowledge was examined in two ways. First, following J. H. Howard and colleagues (2008), participants were given a recognition block in which they observed each of the 64 triplets (including 16 foils that never occurred) and they judged whether each had occurred frequently or infrequently responding by key press. Next, participants were interviewed directly about their knowledge of the task structure using a questionnaire of both open-ended and multiple-choice questions. Finally, participants were told there was in fact a predictive relationship and they were asked to describe it.
Results

Trials in which participants did not respond were excluded ($M = 3.5$ of 1,680 trials for young and $M = 15.5$ for older adults). Statistical significance was set at $\alpha = .05$ and for analyses of variance (ANOVAs), when Mauchly’s test indicated a violation of sphericity, a Greenhouse–Geisser correction was used.

Learning

The TPT is structured such that some targets are more likely than others to follow specific cues; for present purposes, predictions of the likely targets will be termed optimal predictions (OPs). Learning was quantified by examining the proportion of trials in a given block or session on which participants made the OP for the cues presented. First, this OP was analyzed using an age (young vs old) by session (1–6) repeated-measures ANOVA. Figure 2A displays the proportion of OP across sessions for both age groups. As predicted, there was a main effect of age, $F(1,26) = 12.41$, $p = .002$, $\eta_{p}^{2} = .323$, with older adults making the OP less often ($M = 0.44$) than young adults ($M = 0.62$). There was also an effect of session, $F(5,130) = 32.00$, $p < .001$, $\eta_{p}^{2} = .552$, reflecting an overall gradual increase in OP from Session 1 ($M = 0.39$) to Session 6 ($M = 0.60$). The Age × Session interaction was not significant ($p > .10$).

To determine if the age difference apparent in Session 1 existed at the beginning of the task or emerged with experience, Figure 2B displays the OP within Session 1 by 70-trial block for both age groups. Importantly, this analysis showed a significant Age × Block interaction, $F(3,78) = 8.52$, $p < .001$, $\eta_{p}^{2} = .247$, indicating that age differences emerged in Session 1. Specifically, follow-up analyses revealed that older adults do not improve in OP during Session 1 ($p > .10$), whereas young adults do, $F(3,39) = 17.85$, $p < .001$, $\eta_{p}^{2} = .579$. These analyses indicate that age-related differences in learning the cue–target relationships occur early, but that later rates of learning are similar for the two groups.

An age (young vs old) by session (1–6) by prediction (OP vs NP) ANOVA revealed a main effect of age, $F(1,26) = 6.73$, $p = .015$, $\eta_{p}^{2} = .206$, with older adults ($M = 1,243.07$ ms) significantly slower overall than young adults ($M = 803.98$ ms). There was also a main effect of prediction, $F(1,26) = 35.67$, $p < .001$, $\eta_{p}^{2} = .578$, with NP...
To break apart this three-way interaction, follow-up two-way Session × Prediction ANOVAs were performed separately for each age group, and one-way session ANOVAs were performed for each prediction type. These revealed that older adults showed a significant Prediction × Session interaction, $F(5,130) = 4.63$, $p = .005$, $\eta^2_p = .151$, and Prediction × Session interactions, $F(5,130) = 4.04$, $p = .007$, $\eta^2_p = .134$. However, these were conditioned by a significant Age × Prediction × Session interaction, $F(5,130) = 2.79$, $p = .040$, $\eta^2_p = .097$.

Recognition and Explicit Knowledge

Explicit knowledge of the underlying triplet structure was assessed by the average frequency rating (0 = infrequent, 1 = frequent) for each triplet type on the triplets recognition test. Because mean ratings can range from 0 to 1, an average rating of 0.5 represents maximum uncertainty about the triplet frequency. As seen in Figure 3B, an Age × Triplet Type (high, low, and foil) mixed-model ANOVA revealed a significant Age × Triplet Type interaction, $F(3,78) = 13.81$, $p < .001$, $\eta^2_p = .347$. Follow-up one-sample tests comparing these ratings to the point of maximum uncertainty, 0.5, found that young adults rated high-frequency triplets as occurring frequently (significantly $> .5$), $t(13) = 7.39$, $p < .001$, whereas low-frequency and foil triplets were rated as infrequent, $t(13) = -3.59$, $p = .003$ and $t(13) = -7.72$, $p < .001$, respectively. Additionally, as shown in Table 2, dependent $t$ tests revealed that young adults were able to distinguish the three triplet types from each other. In contrast, older adults were only reliably able to judge that the high-frequency triplets were frequent, $t(13) = 2.59$, $p = .022$, whereas remaining uncertain about the low-frequency triplets and foils. However, dependent $t$ tests suggest that older adults were able to distinguish among the different triplet types.

We next examined the relationship between the individual recognition scores and the late AL scores reported earlier, reasoning that these late scores best captured the degree of AL. To summarize the overall recognition performance for each individual, we determined the difference in frequency ratings for high and low triplets, creating a
composite recognition score. These were then correlated with the AL scores for each group. As shown in Figure 3C, for young adults, the AL score was positively related to recognition, $R = .849, p < .001$, suggesting that for them, the AL score reflects explicit knowledge of the cue–target relationships. In contrast, for older adults, there was no relationship between AL score and recognition, $R = .056, p = .849$, and the group difference in correlation was significant, $z = 2.81, p = .005$ (Fisher’s $r$-to-$z$). Hence, young adults demonstrated explicit knowledge of both high- and low-frequency events, and this was related to their learning on the TPT. Older adults could also identify high-frequency events, but low-frequency events were more nebulous for them and there was no clear relationship between their explicit knowledge and TPT learning.

Correlations Between Neuropsychological Measures and Learning

To obtain insight into the cognitive components that might support TPT learning, we examined the relationship between late AL scores and performance on standardized neuropsychological tests, as shown in Figure 3D. For young adults, there was a significant positive relationship between learning and working memory, as measured by Digit Span Backwards, $R = .665, p = .010$; those who had better working memory learned more. For older adults, this correlation was not significant, $R = .247, p = .394$. Instead, for them there was a significant relationship between learning and processing speed, as measured by Digit Symbol Coding, $R = .560, p = .037$, and verbal intelligence, as measured by the North American Adult Reading Test, $R = −.538, p = .047$, such that those older adults who had faster processing speed and better verbal intelligence were better learners. Neither of these correlations was significant for young adults, $R = .453, p = .104$ and $R = −.039, p = .895$, processing speed and verbal intelligence, respectively.

Overall, these analyses suggest that there may be age-related differences in the cognitive skills that support learning on the TPT, with the learning in young, but not older, adults supported by working memory. For older adults, learning on this task is associated with higher general cognitive function.

Table 2. Triplets Recognition Ratings a Paired Samples t Tests

<table>
<thead>
<tr>
<th>Group</th>
<th>Comparison</th>
<th>$t$</th>
<th>$p$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young</td>
<td>High vs low</td>
<td>6.16</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>Low vs foil</td>
<td>3.08</td>
<td>.009</td>
</tr>
<tr>
<td></td>
<td>High vs foil</td>
<td>8.11</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Older</td>
<td>High vs low</td>
<td>2.31</td>
<td>.038*</td>
</tr>
<tr>
<td></td>
<td>Low vs foil</td>
<td>2.86</td>
<td>.013</td>
</tr>
<tr>
<td></td>
<td>High vs foil</td>
<td>3.03</td>
<td>.010</td>
</tr>
</tbody>
</table>

Notes. 0 = infrequent; 1 = frequent.

*Uncorrected; not significant with Bonferroni ($t_{crit} = 2.75$, $p_{crit} = .017$) correction.
DISCUSSION
The present study investigated how young and older adults learn to use sequential regularities in their environment to make predictions. There were two major findings. First, both young and older adults demonstrated learning of subtle probabilistic cue–target relationships in that they were able to use this knowledge to predict the optimal target location increasingly with practice. However, an age deficit in learning emerged early in training and performance differences persisted across extended practice. Second, there was evidence that the two groups relied on different AL systems. Each finding will be elaborated in more detail below.

Both age groups learned the predictive relationships in that the proportion of OPs increased significantly for each with practice. In addition, OPs were made significantly faster than the NPs for both groups, suggesting that people were more confident and/or less uncertain when making optimal than NPs.

Although both groups showed learning, there is evidence that the older adults not only learned less but that they learned differently. Collectively, several findings suggest that the young relied primarily on the fast AL system, which is often characterized as flexible, explicit, and dependent on working memory, whereas the older group relied on the slow AL system, which is inflexible, and often characterized as implicit.

First, during the TPT task, young adults learned the cue–target relationships more quickly than older adults, consistent with their relying on a fast AL system. That is, only the young adults revealed a significant increase in OPs during the first session. This may be due in part to the fact that young adults quickly realized that foils never occurred, as evidenced by the fact that when the young adults made nonoptimal decisions, they predicted foils significantly less than older adults within Session 1 (mean proportion foils = .15 and .26 for young and older adults, respectively, t(26) = −2.25, p = .036).

Second, not only did this initial age difference in OP persist with extended practice, but additional analyses also indicated that the nature of the nonoptimal responses differed between age groups. That is, in Sessions 5 and 6, older adults persisted with the same NPs proportionally more often than young adults, rather than changing their responses due to feedback (Session 5: M = 0.42 and 0.29 for older and young adults, respectively, t(26) = −2.40, p = .024; Session 6: M = 0.39 and 0.27 for older and young adults, respectively, t(26) = −2.60, p = .015). This is consistent with the interpretation that the inflexible, slow AL system is dominant for older adults.

Third, the pattern of change in response times with practice is qualitatively different for the age groups; only young adults became faster with practice, whereas older adults revealed stable overall response time for OPs and slowed responding for NPs. In addition, the older adults made increasingly faster optimal compared with NPs with practice and this prediction-type effect increased over sessions for older, but not for young adults. This pattern suggests that older adults become increasingly sensitive to the stochastic relationships between cues and targets throughout the task, as might be expected for the slow associative system.

Fourth, there were age differences in the pattern of correlations between neuropsychological tests and TPT learning; young adults revealed a positive correlation between learning and working memory, but older did not. In contrast, older adults revealed a correlation between learning and processing speed and verbal intelligence, but young did not. This pattern is consistent with the notion that the young, but not older adults’ learning involved the fast associative system that calls on working memory.

Fifth, recognition judgments suggest that the young adults gained more explicit knowledge about the predictive relations in the TPT than the older adults. Although both groups judged that high-frequency triplets occurred more often than low-frequency triplets, only young adults rated low-frequency triplets and foils as occurring infrequently. In contrast, the older adults were more uncertain about how often these infrequent triplet types occurred. Finally, for young adults, recognition test performance correlated significantly with TPT learning, with better learners showing higher recognition scores, but for older adults, recognition scores were unrelated to TLT learning.

Taken together, these results indicate that young adults’ learning occurred quickly and was related to explicit recognition and working memory ability. In contrast, the older adults’ learning occurred slowly and was unrelated to explicit recognition or working memory. This pattern is consistent with the hypothesis that older adults are not engaging the fast AL to the same extent as young adults.

Our interpretation that older adults are using the slow, striatal-based AL system on the TPT may seem inconsistent with other studies of sequence learning. In these earlier studies, although young adults shifted from recruiting the medial temporal lobe (MTL) early to recruiting the striatum later in learning, older adults tended to rely on the MTL throughout the task (Rieckmann & Bäckman, 2009; Simon et al., 2012). As we will detail below, we hypothesize that differences in task demands and the strategies used by participants led to a different pattern of engagement of these AL systems on the TPT.

One of the more salient characteristics of learning and decision making by older adults is that they tend to have an initial preference for relatively simple strategies (Mata & Nunes, 2010; Mata, Schooler, & Rieskamp, 2007). Paradoxically, during the postexperimental interview, the majority of participants (N = 8 and 6 for older and young adults, respectively) reported using the cue pair to make predictions as opposed to one cue alone (N = 1 and 4 for older and young adults, respectively) or another strategy (N = 5 and 4 for older and young adults, respectively).
It has been suggested that older adults perform more poorly than young adults on tasks that require information integration and are less accurate than young adults when they use an integrative strategy (Ashby, Noble, Filoteo, Waldron, & Ell, 2003; Maddox, Pacheco, Reeves, Zhu, & Schnyer, 2010). Perhaps participants in both age groups were using the more intensive, integrative cue-pair strategy due to task demands (i.e., people were told from the outset that they should “try to remember which circle was correct so they could choose it the next time they saw that sequence”). However, older adults had more trouble implementing this strategy, contributing to the age deficit in performance on this task.

Taken together, we think that most participants are using a cue-pair strategy on the TPT, which places a high load on working memory because participants had to keep track of feedback for 16 different cue pairs as they performed this task. We speculate that this high load was too great for the fast associative system of older adults, leading them to rely on the slow associative system for their predictions. The fact that age-related deficits in performance persisted is consistent with earlier findings that the efficiency of this slow associative system declines with age, likely reflecting striatal declines (Rieckmann et al., 2010; Simon et al., 2012). Thus, it is likely that declines in both systems contributed to the age deficit on the TPT; however, research directly testing this hypothesis is needed.

Implications and Conclusions

The ability to actively learn about the stochastic relationships among events in our environment and use this knowledge to generate predictions is a hallmark of adaptive behavior. Recent evidence suggests age-related deficits in decision making are due to difficulties older adults have in learning these relationships (Mata et al., 2011). The research presented here is consistent with this, suggesting that age differences in prediction could be due not only to older adults not learning as well as younger adults but also to their learning differently. As research in decision making expands to investigate the role of different learning systems (Bornstein & Daw, 2012; Daw, Kakade, & Dayan, 2002; Gläscher, Daw, Dayan, & O’Doherty, 2010), it is important to consider how age-related changes in these systems affect the learning that underlies adaptive behavior.

In summary, although older adults are able to learn statistical relationships in a sequential prediction task, they learn less than young adults and their learning is qualitatively different from that of young adults. More research is needed to understand how age differences in learning can influence the ability of older adults to adapt to their environments.

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References


